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DEPARTMENT OF WATER AFFAIRS
AND FORESTRY

DIRECTORATE OF WATER RESOURCES PLANNING

BREEDE RIVER BASIN STUDY

GROUNDWATER RESERVE DETERMINATION

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DEPARTMENT OF
WATER AFFAIRS AND FORESTRY

BREEDE RIVER BASIN STUDY

GROUNDWATER RESERVE DETERMINATION

Final

MAY 2003

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BREEDE RIVER BASIN STUDY

GROUNDWATER RESERVE DETERMINATION

EXECUTIVE SUMMARY

RESERVE DETERMINATIONS UNDERTAKEN FOR THE BREEDE RIVER BASIN STUDY

Environmental sustainability forms one of the cornerstones of the National Water Act. In recognition of this, and to provide the information that would be required to ascertain the availability of water at particular locations in the Breede River catchments and to set a Preliminary Reserve in the Breede Water Management Area, a considerable portion of Study resources was directed toward determining the ecological water requirements of the aquatic ecosystems in the catchments of the Breede River.

Reserve determinations were carried out for the following components of the Reserve :

- Groundwater. (The subject of this report.)
- The Papenkuils Wetland, documented in Report PH 00/00/1402 *Papenkuils Wetland Intermediate (Ecological) Reserve Determination (Low Confidence).*
- Riverine water quantity, documented in Report PH 00/00/1302 *Ecological Reserve Determination for Six Representative Sites using the Building Block Methodology*.
- Riverine water quality, documented in Reports PH 00/00/3402 *Ecological Reserve Determination (Water Quality)*, and PH 00/00/3602 *Ecological Reserve Determination (Water Quality) – Recalculation of the Water Quality Reserve*.
- The Breede River Estuary, documented in Report PH 00/00/1102 *Intermediate Determination of Resource Directed Measures for the Breede River Estuary.*

The geographical spread and confidence levels of the determinations were planned to deliver, as far as present knowledge and available resources permitted, Reserve determinations commensurate with the management needs of the Breede River catchments. The Study findings represent scientific estimates of the ecological water requirements of the aquatic ecosystems in the Breede River catchments. The socio-economic implications of the implementation of Reserves at the recommended levels (Ecological Management Categories) should therefore be carefully considered prior to the setting of a preliminary Reserve. Before a comprehensive Reserve can be set, a separate stakeholder consultation process must first take place.

Numerous interrelations exist between the different components of the Reserve in the Breede River catchment. These had to be taken into account to provide an accurate reflection of current and future water availability. This information will also be required when setting a Preliminary Reserve, and to manage the system accordingly. Relatively simple integration procedures were therefore developed during the course of the Study, and the findings of this work are reported on in the *Main Report* of the Study (Report PH 00/00/3102).

Very little experience has thus far been gained in the implementation and management of Reserves in South Africa, and little is known about the effectiveness of the ecological water requirements (EWRs) in achieving the recommended ecological management categories. In recognition of the limited experience available, further study work was approved to explore the implications that the system-wide implementation of recommended EWRs may have on water availability in the Breede catchment. This work is also documented in the *Main Report*.

GROUNDWATER RESERVE DETERMINATION

This report provides, as initial estimates, volumes of recharge to groundwater, the groundwater contribution to baseflow and current groundwater use in the Breede catchment. Existing methodologies were employed to arrive at estimates of the monthly groundwater Reserve and the volume of groundwater available for abstraction without affecting the riparian ecology.

Determinations of the groundwater component of the Reserve were carried out at an intermediate level for two areas in the upper Breede catchment and at a rapid level for twelve areas for the whole of the Breede catchment. The groundwater resource areas for intermediate level determinations were from Wolseley to the Brandvlei Dam and from Worcester to the Nuy Valley. These areas were selected because the groundwater assessment of the Breede River Basin Study, conducted prior to the Reserve, indicated significant groundwater use and potential for further groundwater development in these areas. The boundaries of the groundwater resource areas correspond to quaternary catchment boundaries.

The Groundwater Reserve as defined in National Water Act of 1998, is the quality and quantity of groundwater required to satisfy basic human needs and to protect aquatic ecosystems, in order to secure ecologically sustainable development. In the Breede catchment groundwater for basic human needs (presently set at 25 ℓ/p/d) comprises a very small percentage of the overall resource. Therefore, if one ignores the small volume for basic human needs, the groundwater Reserve can be thought of as the volume that must reach rivers to ensure the integrity of riparian ecology and is most important during low flow periods.

Groundwater is thought to contribute most of the Breede River stream flow in summer, and therefore groundwater abstraction over this period (particularly abstraction close to riparian zones) has the potential to affect low flows essential in meeting the in-stream flow requirements (IFR) of surface watercourses. It must be noted that regional groundwater flow, remote from the riparian zones, must also be accounted for, as this water would also eventually contribute to river flow. The groundwater contribution to baseflow has been estimated using hydrograph separation of naturalised stream flow series from 1927 to 1990.

Three homogenous response units (i.e. within each water resource area for which an intermediate determination was carried out) are recognised in the upper Breede catchment. These are the Table

Mountain Group (Unit A), alluvial aquifers (Unit B) and hillslope-and-valley fractured aquifers (Unit C). The alluvial aquifers are the most utilised aquifers in the upper Breede catchment whereas the TMG aquifers, where most of the groundwater allocation is available, are hardly used. This is usually because of practical constraints of establishing boreholes in mountainous terrain and the distance from irrigable land.

The method used for the intermediate and rapid level determinations are similar except that at the intermediate level, the water resource unit is divided into smaller units based on geohydrological considerations. The groundwater allocation is based on the average annual recharge minus the IFR low maintenance baseflow. An adjustment to the groundwater allocation is proposed and termed the 'usable groundwater contribution to river flow' and equal to the average monthly groundwater contribution to baseflow minus the monthly IFR. This implies that the usable groundwater contribution to river flow is the total groundwater volume that can be allocated as part of the Reserve.

Note:
The protocol for determining the groundwater component of the Reserve (DWAF, 1999) defines the term 'groundwater allocation' as the rate (or volume) at which groundwater can be abstracted on an annual basis without resulting in a significant drop of regional groundwater levels in a catchment over the long-term, and without deterioration of groundwater quality or without causing any other detrimental impact on aquatic ecosystems. It is easy to confuse this term with the total volume of licensed (already allocated) abstractions in a catchment, and for this reason it would probably be wise to revise the terminology of the protocol, and to use a term such as 'sustainable groundwater abstraction volume' instead. To avoid the arbitrary introduction of a new term, and to remain consistent with the protocol in its current form, the term 'groundwater allocation' is adhered to in this report, but must be interpreted as defined here.

Both rapid and intermediate level determinations indicate further potential for groundwater development except in the Ceres Valley where the registration of groundwater use exceeds the allocation. The registration of groundwater use does not necessarily mean that this volume represents an annual average; it is more likely to represent the maximum utilised in times of below average rainfall. Rapid level determinations indicate that in other parts of the upper Breede catchment (i.e. Wolseley and Moordkuil), approximately two-thirds of the groundwater allocation is registered, whereas in all the remaining areas, less than 50% is registered. In many parts of the middle and lower Breede catchment, although there is substantial groundwater allocation available, poor water quality limits the use of groundwater for irrigation.

The groundwater allocation in the area extending from the base of Michell's Pass to the Brandvlei Dam (water resource area 1) is approximately 94 million m^3/a of which about 32 million m^3/a is currently used (or registered). In the area from Worcester to the Nuy Valley, the allocation is approximately 15 million m^3/a and current use about 2,5 million m^3/a. In both water resource areas, the available allocation is available largely from the TMG aquifers but is abstracted from the alluvial aquifers of the Breede Valley. The abstraction rate from the alluvial aquifer already exceeds the groundwater allocation of the alluvial aquifer by a significant amount (e.g. in water resource area 1, the allocation is 3,3 million m^3/a and current abstraction exceeds 20 million m^3/a). The abstracted groundwater is obtained from storage in the alluvial aquifer and is recharged by, inter alia, baseflow fed in summer by groundwater from the TMG. Because of the degree of surface-groundwater interaction in the upper Breede catchment, the groundwater allocation for the alluvial aquifers and TMG need to be managed conjunctively. The site specific conditions of every application for groundwater abstraction need to be considered in addition to the status of the Reserve. In other words, the applicant must indicate the potential impact based on data obtained from test pumping, surrounding boreholes and streams, recharge estimates and time-distance drawdown curves.

Further understanding of areas where rivers are losing (i.e. recharging) to groundwater and where the opposite holds is required before definitive statements can be made on the impact of abstraction on stream flow. This information will require some investment in specialist studies to evaluate the hydraulics in proximity to rivers and streams in proximity to where significant abstraction is taking place. A variety of hydrogeological settings (e.g. consolidated and unconsolidated aquifers) should be studied to evaluate natural variation and the effects of abstraction on stream flow. Without these studies and information gathered from different hydrogeological settings, it will be impossible to develop our understanding of these systems and thereby assist the authorities in protecting the resource.

Groundwater quality considerations are equally important to the Reserve. As a change in the groundwater level could impact the ability of subsurface systems to maintain the Reserve, so too could a change in groundwater quality. Quality of groundwater is important in defining exploitation potential, as usage is dependent on quality criteria. This is particularly relevant in the Breede Valley where relatively low salinity water (EC < 80 mS/m) is required for irrigation of vines and fruit trees. The exploitation potential in large parts of the Middle Breede and in the Lower Breede Valley is limited because of poor groundwater quality. Changes in groundwater quality, particularly in the rate of change, can impact on aquatic ecosystems and therefore is an important component in assessing the reserve.

Deterioration in groundwater quality is probable where heavy abstraction occurs in proximity to naturally saline formations (e.g. the Ecca Formation of the Karoo Group) and under drought conditions. However, irrigation return flows are considered to have a considerably larger role in river salinisation than over-abstraction from aquifers. There is currently no methodology established to determine the Resource Quality Objectives for each geohydrological unit. An interim solution could be to limit any increase in salinity as a result of abstraction to within 15% of ambient levels.

BREEDE RIVER BASIN STUDY

GROUNDWATER RESERVE DETERMINATION

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GROUNDWATER RESERVE DETERMINATION

1. INRODUCTION

1.1 TERMS OF REFERENCE

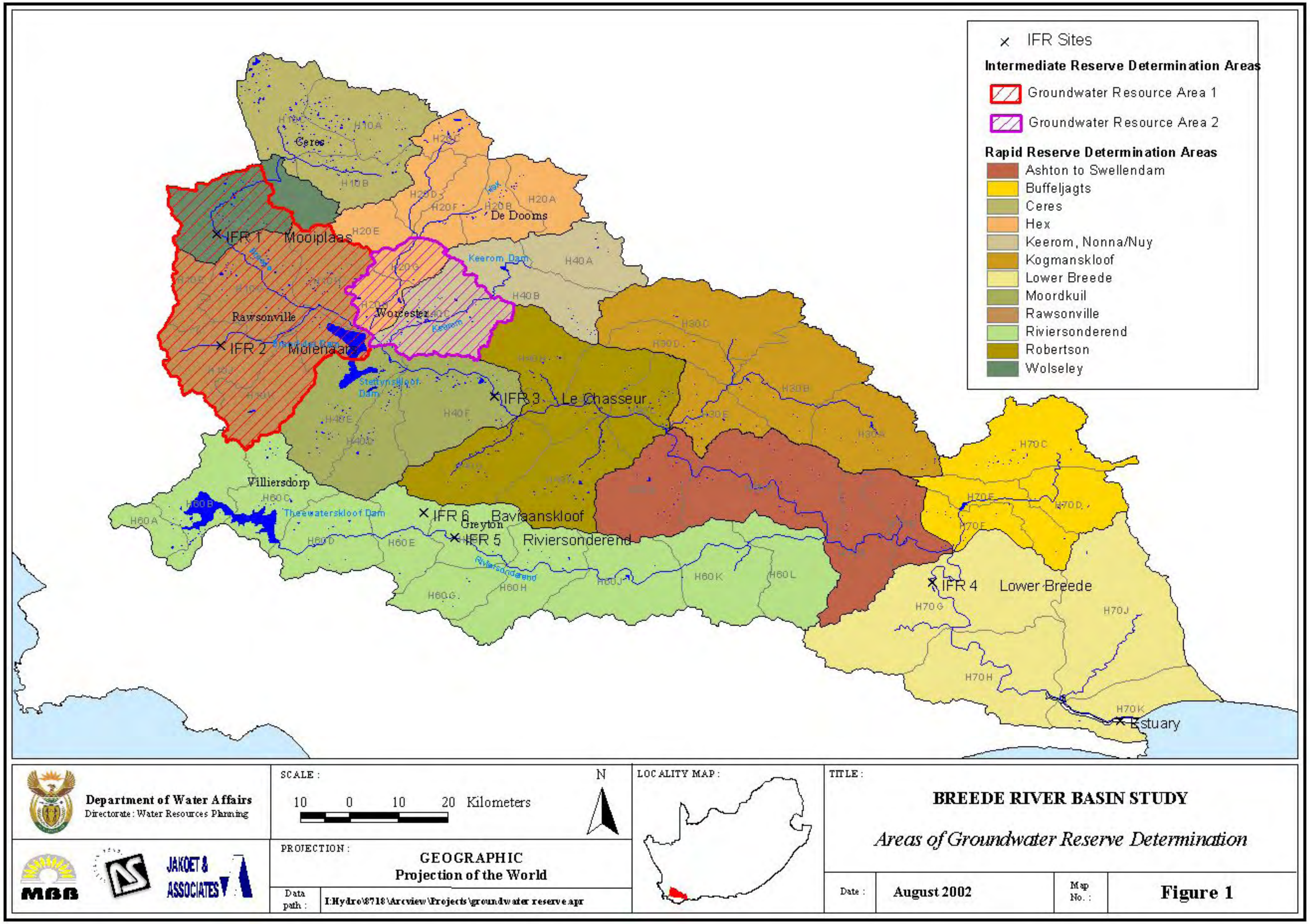
Groundwater Consulting Services were notified in May 2001 of the approval of contingency funding for Reserve determination work not originally included in the terms of reference of the Breede River Basin Study. The purpose of the Reserve determinations is primarily to inform the basin study of the availability of water at particular locations in the basin and are a legal requirement for issuing of water abstraction licences.

Rapid level Groundwater Reserve determinations were carried out for twelve areas comprised of grouped quaternary catchments where similar hydrogeological conditions prevail. The selection of these areas was also guided by the availability of naturalised flow sequences. The in-stream flow requirement (IFR) was determined (Southern Waters) for each of the areas.

Intermediate level Groundwater Reserve determinations were carried out for two areas in the upper Breede Basin. These areas were selected as there is significant groundwater use taking place and potential for further groundwater development. The initial proposal for intermediate determinations separated the Rawsonville area from the area from Wolseley to Worcester, however, the hydrogeology of the Valley does not readily allow for separation of areas west and east of the Breede River and is therefore included in one large unit (see below).

The more northerly area, henceforth referred to as water resource unit 1, extends south from Wolseley to where the road bridge crosses the Breede River near the Brandvlei Dam (Die Nekkies), incorporating the Rawsonville alluvial aquifer. This area approximately corresponds to the following quaternary catchments – H10F, G, E, J, K, L. and was selected because of the importance of groundwater in the Rawsonville area. Irrigated agriculture is reliant on groundwater because of the non-perennial nature of tributaries to the Breede River and the lack of suitable sites for storage of surface run-off. Any potential groundwater abstraction schemes to augment diversions to the Brandvlei Dam has the potential to impact current users and the Papenkuils wetland. The second area where an intermediate level Reserve determination was carried out was from Worcester in an easterly direction to Nuy (water resource unit 2) corresponding to quaternary catchments H20G, H20H and H40C. The groundwater use in this area was initially thought to be higher than subsequent investigation revealed.

The locations of the areas selected for Reserve Determinations are shown on Figure 1 overleaf.



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PROJECTION : **GEOGRAPHIC**
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TITLE :

BREEDE RIVER BASIN STUDY

Areas of Groundwater Reserve Determination

Date : **August 2002**

Map No. : **Figure 1**

1.2 CONCEPT OF THE GROUNDWATER RESERVE

The groundwater Reserve as defined in National Water Act of 1998 is the quality and quantity of groundwater to:

- Satisfy basic human needs by securing a basic water supply for people who are now or who will, in the foreseeable future, be relying on, taking water from, or being supplied by, the relevant water resource, and
- To protect aquatic ecosystems, in order to secure ecologically sustainable development and use of the relevant water resource.

In the Breede Basin, groundwater for basic human needs (presently set at 25 ℓ/p/d) comprises a very small percentage of the resources capacity and consumption. Therefore, if one ignores the small volume for basic human needs, the Groundwater Reserve can be thought of as the volume that must reach rivers to ensure the integrity of riparian ecology.

Groundwater is thought to contribute almost exclusively to stream flow in summer and therefore groundwater abstraction over this period has the potential to affect low flows essential in meeting the IFR of surface watercourses. Groundwater abstraction from alluvial aquifers or boreholes close to rivers (e.g.<100m) is expected to result in a more rapid decline in baseflow compared to abstraction from boreholes more distant from stream channels. Boreholes actively pumping groundwater cause a lowering of the water level around them (or drawdown cone) that is greatest immediately around the borehole and decreases with distance from the borehole. The shape of the drawdown cone is a function of the abstraction rate, transmissivity of the aquifer and the presence of any boundaries. The greater the abstraction and the presence of groundwater boundaries increase the extent of the drawdown cone, whereas the greater the transmissivity of the aquifer, the less the extent of the drawdown cone. These basic principles may be used to define exclusion zones around, for example, streams in which there are constraints on either the yield the borehole can be pumped at, or the amount that may be abstracted.

As groundwater levels in boreholes are usually at their lowest levels toward the end of the irrigation season (i.e. in March/April), the extent of the drawdown cone is greatest toward the end of summer. This is also when flow in rivers is at a minimum and when there is greatest potential for groundwater abstraction to affect the reserve and the in-stream flow requirements. In many circumstances the drawdown cone will not extend to streams or sensitive areas before the end of the irrigation season and there may be little reduction in baseflow. Recharge of aquifers from rainfall and stream flow in winter usually re-establishes groundwater levels to their pre-irrigation season level. However, incomplete recovery of groundwater levels can occur when the exploitation potential of the aquifer is exceeded or when there is below average recharge over the following winter. In these situations, baseflow to rivers is likely to be affected until an exceptional recharge season occurs, or abstraction is reduced. If abstraction of groundwater that would have contributed to baseflow (headwaters) takes place, low river flow periods may well be extended. The management of boreholes abstracting in proximity to rivers could be controlled on the basis of the volume abstracted, the period of abstraction and the drawdown allowed.

1.3 GROUNDWATER ALLOCATION

The term 'groundwater allocation' is defined as the rate (or volume) at which groundwater can be abstracted on an annual basis without resulting in a significant drop of regional groundwater levels in a catchment over the long-term, and without deterioration of groundwater quality or without causing any other detrimental impact on aquatic ecosystems. The protocol for determining the groundwater allocation (DWAF, 1999) requires subtracting the basic human needs and the groundwater component of baseflow from the Harvest Potential (defined in 2.2.1) to arrive at an annual volume available for abstraction. The use of harvest potential volume has been replaced by recharge potential in this report. Justification for this is given in Section 2.2.

In the United Kingdom a similar system is in place to arrive at a groundwater volume available for abstraction (although it does not consider basic human needs separately) and requires the following (Kirk and Soley, 2000):

- obtain estimate for long-term groundwater recharge;
- then subtract the percentage that accounts for unreliability of recharge
- further subtract the percentage that satisfies river and environmental requirements and
- allocate the remaining percentage for human use.
- The Precautionary Principle applies so that empirically deduced allocations are conservative.

Note:
The protocol for determining the groundwater component of the Reserve (DWAF, 1999) defines the term 'groundwater allocation' as the rate (or volume) at which groundwater can be abstracted on an annual basis without resulting in a significant drop of regional groundwater levels in a catchment over the long-term, and without deterioration of groundwater quality or without causing any other detrimental impact on aquatic ecosystems. It is easy to confuse this term with the total volume of licensed (already allocated) abstractions in a catchment, and for this reason it would probably be wise to revise the terminology of the protocol, and to use a term such as 'sustainable groundwater abstraction volume' in stead. To avoid the arbitrary introduction of a new term, and to remain consistent with the protocol in its current form, the term 'groundwater allocation' is adhered to in this report, but must be interpreted as defined here.

1.4 GROUNDWATER QUALITY

Groundwater quality considerations are equally important to the Reserve. As a change in the groundwater level could impact the ability of subsurface systems to maintain the Reserve, so too could a change in groundwater quality. Quality of groundwater is important in defining exploitation potential, as usage is dependent on quality criteria. This is particularly relevant in the Breede Valley where relatively low salinity water (EC < 80 mS/m) is required for irrigation of vines and fruit trees. The exploitation potential in large parts of the Middle Breede and in the Lower Breede Valley is limited because of poor groundwater quality. Changes in groundwater quality, particularly in the rate of change, can impact on aquatic ecosystems and therefore is an important component in assessing the reserve.

Deterioration in groundwater quality is probable where heavy abstraction occurs in proximity to naturally saline formations (e.g. the Ecca Formation of the Karoo Group) and under drought conditions. However, irrigation return flows are considered to have a considerably larger role in river salinisation than over-abstraction from aquifers. There is currently no methodology established to determine the Resource Quality Objectives for each geohydrological unit. An interim solution could be to limit any increase in salinity as a result of abstraction to within 15% of ambient levels.

2. RAPID LEVEL RESERVE DETERMINATIONS

2.1 INTRODUCTION

The methodology for rapid level reserve determination is an initial process allowing for a conservative general groundwater allocation in a quaternary catchment or specific area. Subsequent allocations will require more substantial analysis and investigation. The main purpose of the Rapid Reserve Determination (RRD) method for determining the groundwater component of the Reserve is to quantify the groundwater annually available for abstraction without impacting the Reserve using readily available information. As this is a rapid tool, no formal demarcation or classification system is used (i.e. homogenous response units of geohydrological region types) and it is assumed that no groundwater management corrective actions are required. Where it is apparent that aquifers have been impacted by over-abstraction, a higher level of reserve determination is required.

The data used for baseflow separations are cumulative natural flow sequences modelled by hydrologists at Ninham Shand from existing gauged flows or extrapolated for areas where flow data are not available. The flow sequences are from 1927 to 1990. The IFR from IFR sites 1, 3 and 4 were used for the Wolseley, Moordkuil and Bonnievale to Swellendam areas respectively, and Southern Waters provided the remaining IFR flow series at the request of Groundwater Consulting Services. Incremental naturalised flow sequences and IFRs were used for Wolseley, Rawsonville, Moordkuil, Robertson, Bonnievale to Swellendam and the Lower Breede since all flows (and IFRs) derived upstream of the catchment area of concern must be discounted. In this report, the RRDs are superseded by the Intermediate Reserve Determination (IRD) from Wolseley to Nuy, and the latter must be used in preliminary setting of the Reserve.

2.2 METHODOLOGY

2.2.1 DWAF Guidelines (1999) for Resource Directed Measures for Protection of Water Resources

The DWAF guidelines (1999) for Resource Directed Measures for Protection of Water Resources stipulate use of the groundwater Harvest Potential in the Desktop or Planning Estimate Determination calculation. The Harvest Potential is defined as the sustainable volume of groundwater that can be abstracted if environmental and socio-economic issues are not considered. A national groundwater harvest potential map of the Republic of South Africa (Seymour, 1995; Baron *et al*, 1998) has been compiled which utilised the data sets compiled by Haupt (1995).

Harvest Potential is determined from the estimated recharge and storage capacity of aquifers. The recharge is based on historic rainfall data and storage determined by a coefficient based on geology and dimension of the aquifer. Since the Harvest Potential does not allow for environmental considerations, Haupt (1999) assigned the groundwater contribution to stream flow (or baseflow) a percentile of Mean Annual Run-off (MAR) as defined by the WR90 mean monthly flow duration curves and assumed the 75th percentile to be appropriate (i.e. 75% of the time, the flow in rivers is due to groundwater). Subtraction of the 75th percentile of MAR (WR90) from the Harvest Potential then gives the annual volume of groundwater that can be abstracted from a catchment on a sustainable basis without impacting the Reserve significantly (DWAF, 1999).

The use of Harvest Potential and the 75th percentile of (WR90) MAR time series has been criticised by practitioners working with these data sets. Reasons include over-estimation of groundwater contribution to baseflow (i.e. the 75th percentile of MAR also includes interflow which is not generally available for groundwater abstraction) in wetter parts of the country, (giving an underestimation of the groundwater allocation) and unsuitability of WR90 in representing flow regimes at the resolution required for Reserve determinations. For these reasons, the methodology recently proposed by the RDM office has been utilised in preference to that in the DWAF (1999) guideline.

2.2.2 Proposed Methodology for the Breede Basin

Recharge

A recent proposal from the RDM office of DWAF regarding the methodology for preliminary groundwater reserve quantification is to utilise recharge estimates in place of the Harvest Potential. There are a number of 'off-the-shelf' models that can be used for recharge estimates, and these usually have extensive data requirements. However, at a preliminary level of reserve determination and on a regional scale, as in the case of the Breede Basin Study, a simple method of estimating average annual recharge is considered more appropriate.

Recharge estimates were made in the Breede Basin Groundwater Study (GCS, 2001) based on a percentage of mean annual rainfall multiplied by a coefficient determined by the geology. This recharge estimate method is similar to that for determining Harvest Potential but does not consider mean annual run-off in its determination. Storage is considered in the assignment of a geological coefficient (see Appendix A). The recharge potential estimates do not include slope or evapotranspiration as factors affecting recharge; however, in the mountainous recharge zones of the Breede Basin, steep topography (and dip of strata) is likely to play an important role in reducing recharge volumes since a significant component of infiltrating rainfall flows rapidly to streams as interflow over periods of days to weeks after rainfall events. Based on the above, the recharge potential must be greater than the groundwater contribution to stream flow plus any abstraction, to avoid a negative impact on the Reserve. However, if groundwater is abstracted high up in the catchment, it would reduce the volume of groundwater available further down gradient in the catchment. This effect would be remedied partially by recharge taking place progressively along the catchment.

Groundwater contribution to baseflow

The RDM office proposes the use of hydrograph separation techniques (specifically that developed by Smakhtin, 2000) to provide a better indication of the groundwater contribution to stream flow than the 75th percentile of WR90 given in the DWAF guidelines of 1999. Smakhtin recommends (2001) using a coefficient of 0.925 in the hydrograph separation algorithm for regions where MAPs are in the range of 600 mm to 1 100 mm and 0.945 where the MAP is less than 600 mm. These coefficients applied to naturalised flow sequences in the Breede Basin lead to baseflow components as much as 60% of MAR. This is considered high, even for the mountain catchments areas of the Breede Basin.

The baseflow derived from Smakhtin's algorithm includes both the interflow component of the hydrograph as well as the groundwater contribution to stream flow. To arrive at a value for the groundwater contribution to baseflow requires modification of the hydrograph separation to reflect those flows considered to derive undeniably from groundwater. This can be achieved, in the case of Smakhtin's algorithm, by increasing the coefficient closer to 1 which results in a hydrograph separation considered more representative of true groundwater flow to rivers. The use of a higher coefficient values (e.g. 0.9980) in Smakhtin's algorithm to give a lower baseflow value representative of the groundwater contribution has proved problematic for long time series (e.g. > 20 years) .

Herold's hydrograph separation technique has been used instead of Smakhtin's in this report and has the advantage of having 3 coefficients that can be modified to derive a 'best-fit' to the naturalised flow sequence. An example of Herold's hydrograph separation technique is provided in Figure 2 and shows that groundwater (contribution to baseflow) comprises nearly all stream flow in summer when stream flow is at a minimum. In winter, baseflow (including the groundwater contribution to baseflow) is greater than in summer but includes a significant component of interflow, which has a relatively quick residence time in the ground. Although baseflow (interflow plus the groundwater contribution to baseflow) comprise as much as 50% of total runoff, the component directly attributable to groundwater in the upper Breede catchment varies from 10% to 20% of MAR (GCS, 2001).

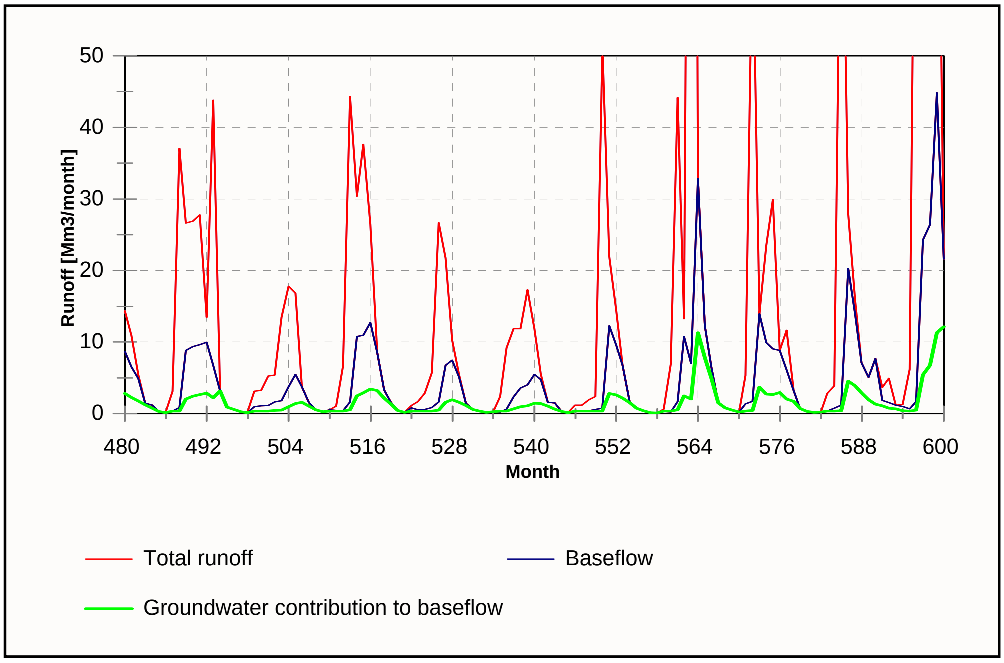


Figure 2 : Hydrograph separation indicating baseflow and the groundwater contribution to baseflow

Groundwater allocation

The groundwater Reserve (sum of the groundwater contribution to baseflow and basic human needs) is a conservative volume and, by implication, makes allowance for all of the groundwater contribution to reach streams and rivers. The in-stream-flow-requirements (low maintenance baseflow) are frequently less than the groundwater contribution to baseflow and therefore the monthly differences between the groundwater contribution to baseflow and IFR should, theoretically, be available for abstraction. It is suggested that this volume be referred to as the 'usable groundwater contribution to river flow' (Figure 3) and that it be added to the difference between the recharge potential and the groundwater Reserve.

The 'usable groundwater contribution to river flow' is derived monthly from the difference between the monthly groundwater contribution to baseflow and IFR and is predominantly available in summer months (Table 1). In months where the IFR is greater than the groundwater contribution, interflow and surface flow meet most of the IFR requirements and therefore all the groundwater contribution to baseflow should be available for abstraction. However, in the Breede Basin in months where the IFR requirements are met largely by run-off and the groundwater contribution to baseflow is theoretically available, there is no demand for groundwater. Hence, the seasonal availability of this usable groundwater contribution to river flow determines whether it is added to the groundwater allocation. The precautionary principle dictates that in months where the total IFR exceeds the groundwater contribution to baseflow, there is no usable groundwater contribution. (see Table 1).

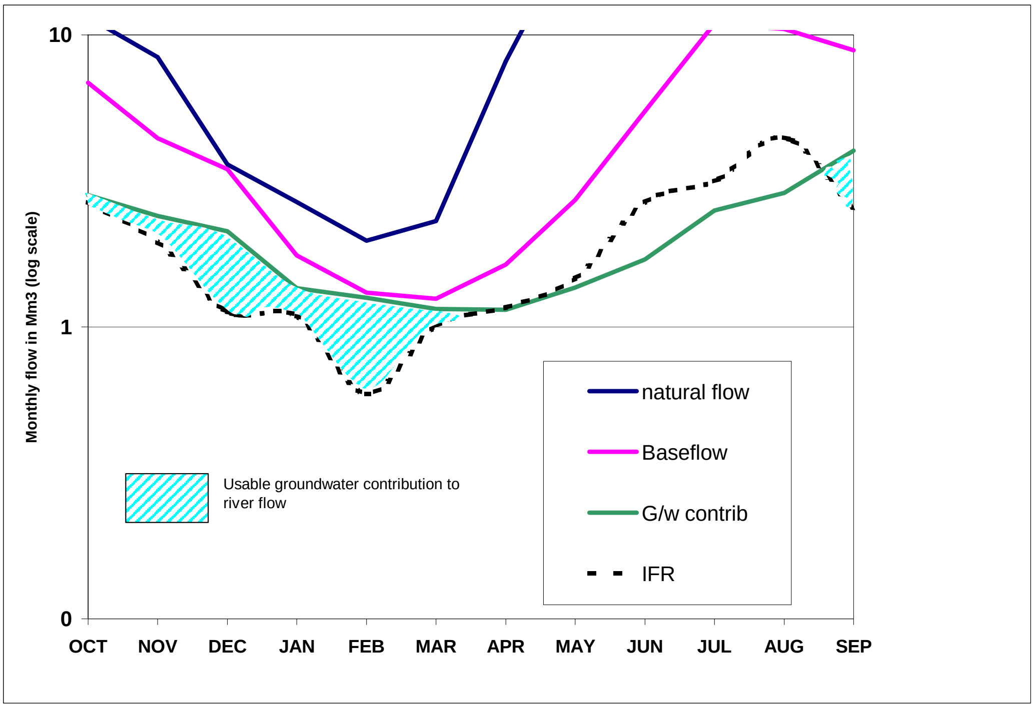


Figure 3 : Representation of the 'usable groundwater contribution to river flow'

TABLE 1 : CALCULATION OF THE 'USABLE GROUNDWATER CONTRIBUTION TO RIVER FLOW' (ADDED TO GROUNDWATER ALLOCATION) FOR WOLSELEY AREA (Mm^3)

Month	Incremental natural flow	Incremental Baseflow	G/w contrib	IFR SITE1	H1H03	Incremental IFR	usable g/w contribution
OCT	11.49	6.85	2.83	5.09	2.42	2.67	0.15
NOV	8.40	4.43	2.40	3.06	1.11	1.95	0.45
DEC	3.60	3.47	2.12	1.61	0.48	1.13	0.99
JAN	2.68	1.76	1.36	1.47	0.38	1.09	0.27
FEB	1.97	1.31	1.26	0.97	0.38	0.59	0.67
MAR	2.31	1.25	1.15	1.34	0.33	1.01	0.14
APR	8.12	1.64	1.15	1.79	0.62	1.17	0.00
MAY	22.98	2.72	1.37	2.71	1.24	1.47	0.00
JUN	31.98	5.49	1.70	4.93	2.25	2.68	0.00
JUL	38.29	10.93	2.50	5.89	2.74	3.15	0.00
AUG	44.88	10.48	2.88	8.04	3.59	4.45	0.00
SEP	13.93	8.86	4.01	5.96	3.43	2.54	1.48
TOTAL	**190.62**	**59.19**	**24.72**	**42.84**	**18.96**	**23.89**	**4.16**

To summarise, the groundwater allocation is calculated as follows:

Groundwater Allocation = Recharge Potential – Groundwater contribution to baseflow + 'usable groundwater contribution to river flow' (annual g/w contribution to baseflow – annual IFR).

Groundwater available for allocation is calculated by subtracting estimated current use from the groundwater allocation. Estimates of current groundwater use are based on the results of the registration of water use required in terms of the National Water Act. The registered groundwater use does not imply that this volume is used on an annual basis and probably represents a maximum consumption rate as most users only resort to groundwater in years of low rainfall when dams are not sufficiently filled to last through the irrigation season.

The results are provided in a summarised format in the following section. For more detailed hydrogeological information (e.g. geology and hydraulic characteristics) the reader is referred to the Groundwater Assessment carried out as part of the Breede River Basin Study.

2.3 RESULTS

The groundwater areas rapid groundwater Reserve determinations, their coincident quaternary catchments, and points where surface flow is measured or calculated are presented in Table 2.

TABLE 2: GROUNDWATER AREAS FOR RAPID RESERVE DETERMINATIONS

GROUNDWATER AREAS	QUATERNARY CATCHMENTS	POINTS WHERE SURFACE FLOW IS MEASURED OR CALCULATED
1) Ceres	H10A, B, C	H1H003 gauging station on Breede River at Ceres
2) Wolseley	H10D, F	IFR Site1 on Breede River before confluence with the Wit River
3) Rawsonville	H10E, G, J, H, K, L	Cumulative H100 run-off on Breede River downstream of Brandvlei Dam.
4) Hex	H200A to H	Cumulative run-off for catchment H200 on Hex River before confluence with Breede River.
5) Keerom and Nonna/Nuy	H40A, B, C	Cumulative runoff from H40A, B and C on the Nuy River before confluence with the Breede River
6) Moordkuil	H40 D, E &F	H4017 on Breede River at Le Chasseur (IFR site 3)
7) Robertson	H40G, H, J, K, L	H5H004 on Breede River
8) Kogmanskloof	H30A – E	Total Kogmanskloof run-off (H300) on the Kinga River before-Breede confluence
9) Ashton to Swellendam	H50A, B, H70A, B	IFR Site 4 on Breede River
10) Buffeljags	H70C,D, E, F	Below the Buffeljags dam on the Buffeljags River
11) Riviersondered	H60A-L	Cumulative H600 run-off on the Riviersonderend before confluence with the Breede River
12) Lower Breede	H70G, H, J	Total Breede Basin run-off

2.3.1 Ceres

The naturalised flow sequence used for hydrograph separation is based on the flow series from gauging station H1H003 (just below Ceres Common).

Groundwater Reserve

QUATERNARY CATCHMENTS	RESOURCE UNIT	CATCHMENT AREA (km^2)	RECHARGE POTENTIAL (Mm^3/a)	BASEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	USEABLE GROUNDWATER CONTRIBUTION (Mm^3/a)	GROUNDWATER ALLOCATION (Mm^3/a)	GROUNDWATER ALLOCATION AS % OF RECHARGE POTENTIAL
H10A,B,C	TMG/Bok*	659	31.6	51.8	17.3	0	14.3	45

* TMG = Table Mountain Group and Bok = Bokkeveld Group aquifers.

The groundwater component to the baseflow of the river is 17,3 Mm^3/a or approximately 55% of the recharge potential. The groundwater contribution to baseflow shown in the table above includes regional groundwater flow, which discharges towards the river. The groundwater allocation for the Reserve is calculated as follows:

Groundwater Allocation = ***Recharge Potential – Groundwater contribution + useable g/w contribution to baseflow***

Where

Useable g/w contribution = ***Annual g/w contribution to baseflow – Annual IFR***

According to existing information, groundwater use in the Ceres area exceeds the groundwater allocation. The useable g/w contribution for the Ceres area is thus zero. The groundwater allocation for the Ceres groundwater area is therefore:

Groundwater Allocation = $31.6\ Mm^3/a - 17.3\ Mm^3/a$ = $14.3\ Mm^3/a$

The groundwater allocation is 45 % of the recharge potential.

Groundwater allocation and current use estimate

The results from the registration of water use indicates that groundwater may comprise as much as 40% of water consumption in the Ceres Basin. Indications are that the current registered use of groundwater in the Ceres Basin exceeds the groundwater allocation. This finding implies that in some months the IFR maintenance low flow may not be satisfied. Consequently it is desirable that the situation be monitored.

2.3.2 Wolseley

The naturalised flow sequence used for hydrograph separation is based on the flow series generated for IFR Site 1 (Mooiplaas), which is upstream of the confluence of the Wit and Breede Rivers. The flow series for gauging station H1H003 was subtracted from the IFR Site1 flow series to give an incremental flow series representing flows from quaternaries H10D and F only.

Groundwater Reserve

QUATERNARY CATCHMENTS	RESOURCE UNIT	CATCHMENT AREA (km^2)	RECHARGE POTENTIAL (Mm^3/a)	BASEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	USEABLE GROUNDWATER CONTRIBUTION (Mm^3/a)	GROUNDWATER ALLOCATION (Mm^3/a)	GROUNDWATER ALLOCATION AS % OF RECHARGE POTENTIAL
H10D,F	Alvm/Malm*	348	32.7	59.4	24.7	4.16	12.16	37

* Alvm = alluvial aquifer; Malm = aquifers of the Malmesbury Group.

The groundwater allocation for the Reserve is calculated as follows:

Groundwater Allocation = ***Recharge Potential – Groundwater contribution + useable g/w contribution to baseflow***

Where

Useable g/w contribution = ***Annual g/w contribution to baseflow – Annual IFR***

According to existing information, useable g/w contribution for the Wolsley area is 4.16 Mm^3/a. The groundwater allocation for the groundwater area is therefore:

Groundwater Allocation = $32.7 - 24.7 + 4.16$ = $12.16\ Mm^3/a$

The groundwater allocation is 37 % of the recharge potential.

Groundwater allocation and current use estimate (Mm^3)

Approximately 60% of the groundwater allocation is currently registered.

Month	Incremental natural flow	Incremental Baseflow	G/w contrib	IFR SITE1	H1H03	Incremental IFR	usable g/w contribution
OCT	11.49	6.85	2.83	5.09	2.42	2.67	0.15
NOV	8.40	4.43	2.40	3.06	1.11	1.95	0.45
DEC	3.60	3.47	2.12	1.61	0.48	1.13	0.99
JAN	2.68	1.76	1.36	1.47	0.38	1.09	0.27
FEB	1.97	1.31	1.26	0.97	0.38	0.59	0.67
MAR	2.31	1.25	1.15	1.34	0.33	1.01	0.14
APR	8.12	1.64	1.15	1.79	0.62	1.17	0.00
MAY	22.98	2.72	1.37	2.71	1.24	1.47	0.00
JUN	31.98	5.49	1.70	4.93	2.25	2.68	0.00
JUL	38.29	10.93	2.50	5.89	2.74	3.15	0.00
AUG	44.88	10.48	2.88	8.04	3.59	4.45	0.00
SEP	13.93	8.86	4.01	5.96	3.43	2.54	1.48
TOTAL	**190.62**	**59.19**	**24.72**	**42.84**	**18.96**	**23.89**	**4.16**

SUMMARY		
Recharge	**32.7**	*Calculated as % of mean annual rainfall x geological coefficient*
G/w Reserve	**24.7**	*(I.e. the groundwater contribution to baseflow)*
usable g/w contrib	**4.2**	*Sum of the difference between the g/w Reserve and the incremental IFR*
Gw allocation	**12.1**	*Recharge - G/w reserve + usable g/w contribution*
G/w use	**7.5**	*Estimated from DWAF registration of water users*
Remaining allocation	**4.6**	*Difference between g/w allocation and g/w use*

2.3.3 Rawsonville Area

This groundwater resource area is large due to the extent of the alluvial deposits in the upper Breede Valley and extends from immediately upstream of the confluence of the Wit with the Breede to Brandvlei Dam (see Figure 1). The naturalised flow series and in-stream flow requirements for IFR Site1 have been subtracted from the cumulative flow series for catchment H100 prior to baseflow separation.

Groundwater Reserve

QUATERNARY CATCHMENTS	RESOURCE UNIT	CATCHMENT AREA (km^2)	RECHARGE POTENTIAL (Mm^3/a)	BASEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	USEABLE GROUNDWATER CONTRIBUTION (Mm^3/a)	GROUNDWATER ALLOCATION (Mm^3/a)	GROUNDWATER ALLOCATION AS % OF RECHARGE POTENTIAL
H10E,G,H,K,L	Alvm/Malm*	1052	177.4	182.4	115	23.56	85.96	48.45

* Alvm = alluvial aquifer; Malm = aquifers of the Malmesbury Group.

The groundwater allocation for the Reserve is calculated as follows:

Groundwater Allocation = ***Recharge Potential – Groundwater contribution + useable g/w contribution to baseflow***

Where

Useable g/w contribution = ***Annual g/w contribution to baseflow – Annual IFR***

According to existing information, useable g/w contribution for the Rawsonville area is 23.56 Mm^3/a. The groundwater allocation for the groundwater area is therefore:

Groundwater Allocation ***= 177.4 – 115 + 23.56 =*** ***85.96 Mm^3/a***

The groundwater allocation is 48 % of the recharge potential.

Groundwater allocation and current use estimate (Mm^3)

Month	Natural Flow incremental	incremental baseflow	g/w contrib	IFR (C/D) H100	IFR Site 1	incremental IFR	usable g/w contribution
OCT	23.00	22.949	17.988	14.89	5.089	9.801	8.187
NOV	10.48	10.520	12.460	8.864	3.059	5.805	6.655
DEC	5.69	5.715	7.807	5.726	1.607	4.119	3.688
JAN	5.89	4.332	5.122	5.944	1.473	4.471	0.651
FEB	5.01	4.709	3.899	5.676	0.968	4.708	0.000
MAR	4.42	5.095	3.267	4.757	1.339	3.418	0.000
APR	13.92	9.121	3.224	6.982	1.788	5.194	0.000
MAY	52.44	12.243	3.744	10.232	2.705	7.527	0.000
JUN	99.66	17.459	6.803	18.243	4.925	13.318	0.000
JUL	119.80	24.453	12.332	23.484	5.892	17.592	0.000
AUG	115.47	35.999	17.713	28.314	8.035	20.279	0.000
SEP	62.99	29.839	20.619	22.207	5.962	16.245	4.374
TOTAL	**518.79**	**182.436**	**114.977**	**155.319**	**42.842**	**112.477**	**23.555**

SUMMARY		
Recharge	**177.4**	*Calculated as % of mean annual rainfall x geological coefficient*
Gw Reserve	**115.0**	*(I.e. the groundwater contribution to baseflow)*
usable g/w contrib	**23.6**	*Sum of the difference between the g/w reserve and the incremental IFR*
Gw allocation	**86.0**	*Recharge - G/w Reserve + usable g/w contribution*
Current Use	**24.8**	*Estimated from DWAF registration of water users*
Available allocation	**61.2**	*Difference between g/w allocation and g/w use*

The groundwater allocation for Rawsonville is 86 Mm^3/a but current use, largely around Rawsonville is approximately 25 Mm^3/a leaving an amount still available for allocation of approximately 61 Mm^3/a.

2.3.4 Hex

The whole of the Hex Valley catchment (H200) is included below.

Groundwater Reserve

QUATERNARY CATCHMENTS	RESOURCE UNIT	CATCHMENT AREA (km^2)	RECHARGE POTENTIAL (Mm^3/a)	BASEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	USEABLE GROUNDWATER CONTRIBUTION (Mm^3/a)	GROUNDWATER ALLOCATION (Mm^3/a)	GROUNDWATER ALLOCATION AS % OF RECHARGE POTENTIAL
H20 A – G	TMG/Bok*	837	54.3	41.2	16.5	7.6	45.4	83.6

*TMG = Table Mountain Group and Bok = Bokkeveld Group aquifers.

The groundwater allocation for the Reserve is calculated as follows:

Groundwater Allocation = ***Recharge Potential – Groundwater contribution + useable g/w contribution to baseflow***

Where

Useable g/w contribution = ***Annual g/w contribution to baseflow – Annual IFR***

According to existing information, useable g/w contribution for the Hex area is 7.6 Mm^3/a. The groundwater allocation for the groundwater area is therefore:

Groundwater Allocation ***= 54.3 – 16.5 + 7.6.*** ***=*** ***45.4 Mm^3/a***

Groundwater allocation and current use estimate (Mm^3)

Month	Natural Flow	Baseflow	G/w contrib	IFR	usable g/w contribution
OCT	10.00	5.76	2.56	1.23	1.33
NOV	6.88	3.74	2.04	0.87	1.17
DEC	3.21	2.54	1.55	0.45	1.10
JAN	1.75	1.14	0.95	0.32	0.63
FEB	1.96	0.75	0.56	0.39	0.17
MAR	1.62	0.96	0.48	0.25	0.23
APR	3.65	0.81	0.43	0.33	0.10
MAY	8.85	2.29	0.68	0.39	0.29
JUN	14.81	3.24	0.91	0.71	0.20
JUL	19.90	5.13	1.49	1.03	0.46
AUG	24.40	6.89	2.26	1.45	0.81
SEP	16.69	7.92	2.63	1.52	1.11
TOTAL	**113.71**	**41.17**	**16.54**	**8.94**	**7.60**

SUMMARY		
Recharge	**54.3**	*Calculated as % of mean annual rainfall x geological coefficient*
G/w Reserve	**16.5**	*(I.e. the groundwater contribution to baseflow)*
usable g/w contrib.	**7.6**	*Sum of the difference between the g/w Reserve and the incremental*
Gw allocation	**45.3**	*Recharge - G/w reserve + usable g/w contribution*
G/w use	**20.5**	*Estimated from DWAF registration of water users*
Available allocation	**24.8**	*Difference between g/w allocation and g/w use*

Groundwater use estimate is from the Hex Valley hydrocensus (Papini *et al*, 2001). Groundwater still available for abstraction (including the De Wet area and Worcester – H20G and H) is approximately 25 Mm^3/a.

2.3.5 Keerom and Nonna/Nuy

This area incorporates the mountainous area above the Keerom Dam as well as that part of the catchment in the Breede Valley (i.e. the Nuy River or quaternary catchment H40C). The different areas are geohydrologically different but have been combined because of the available flow series.

Groundwater reserve

QUATERNARY CATCHMENTS	RESOURCE UNIT	CATCHMENT AREA (km^2)	RECHARGE POTENTIAL (Mm^3/a)	BASEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	USEABLE GROUNDWATER CONTRIBUTION (Mm^3/a)	GROUNDWATER ALLOCATION (Mm^3/a)	GROUNDWATER ALLOCATION AS % OF RECHARGE POTENTIAL
H40 A, B, C	TMG/Bok/Malm*	700	27.2	5.4	4.7	4.07	26.57	97.6

* TMG = Table Mountain Group; Bok = Bokkeveld Group aquifers and Malm = Malmesbury Group aquifers.

The groundwater allocation for the Reserve is calculated as follows:

Groundwater Allocation ***=*** ***Recharge Potential – Groundwater contribution + useable g/w contribution to baseflow***

Where

Useable g/w contribution = Annual g/w contribution to baseflow – Annual IFR

According to existing information, useable g/w contribution for the Keerom and Nonna/Nuy area is 7.6 Mm^3/a. The groundwater allocation for the groundwater area is therefore:

Groundwater Allocation = 27.2 – 4.7 + 4.07 = 26.57 Mm^3/a

The groundwater allocation is 97.6 % of the recharge potential.

Groundwater allocation and current use estimate (Mm^3)

Month	Natural Flow	Baseflow Herold	G/w contrib	IFR Low maintenance	usable g/w contribution
OCT	1.09	0.69	0.56	0.10	0.47
NOV	0.88	0.58	0.54	0.08	0.46
DEC	0.55	0.47	0.46	0.05	0.41
JAN	0.41	0.30	0.32	0.05	0.27
FEB	0.29	0.22	0.24	0.04	0.20
MAR	0.23	0.22	0.22	0.03	0.19
APR	0.46	0.22	0.23	0.03	0.20
MAY	0.59	0.29	0.28	0.02	0.26
JUN	0.92	0.34	0.30	0.04	0.26
JUL	1.11	0.47	0.36	0.05	0.31
AUG	2.15	0.76	0.60	0.10	0.50
SEP	1.37	0.82	0.63	0.09	0.53
	10.07	5.38	4.74	0.67	4.07

SUMMARY		
Recharge	27.2	*Calculated as % of mean annual rainfall x geological coefficient*
G/w Reserve	4.7	*(i.e. the groundwater contribution to baseflow)*
usable g/w contrib.	4.1	*Sum of the difference between the g/w Reserve and the incremental IFR*
G/w allocation	26.6	*Recharge - G/w Reserve + usable g/w contribution*
G/w use	3.2	*Estimated from DWAF registration of water users*
Available allocation	23.4	*Difference between g/w allocation and g/w use*

Almost 90% of the groundwater allocation is still available. Most of this groundwater is available in the Keerom basin (H40A and B) where it is estimated that two-thirds of the recharge to this basin takes place.

2.3.6 Moordkuil

The catchments of the Modder, Hoeks, and Doring Rivers comprise this area and it extends downstream of the Brandvlei Dam to as far as Le Chasseur or IFR Site 3 on the Breede River (Figure 1).

Groundwater Reserve

QUATERNARY CATCHMENTS	RESOURCE UNIT	CATCHMENT AREA (km^2)	RECHARGE POTENTIAL (Mm^3/a)	BASEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	USEABLE GROUNDWATER CONTRIBUTION (Mm^3/a)	GROUNDWATER ALLOCATION (Mm^3/a)	GROUNDWATER ALLOCATION AS % OF RECHARGE POTENTIAL
H40 D, E, F	TMG/Bok *	812	27.3	43.5	17.5	0	9.8	35.9

* TMG = Table Mountain Group and Bok = Bokkeveld Group aquifers.

The groundwater allocation for the reserve is calculated as follows:

Groundwater Allocation = ***Recharge Potential – Groundwater contribution + useable g/w contribution to baseflow***

Where

Useable g/w contribution = ***Annual g/w contribution to baseflow – Annual IFR***

According to existing information, useable g/w contribution for the Moordkuil area is zero. The groundwater allocation for the groundwater area is therefore:

Groundwater Allocation ***= 27.3 – 17.5*** = ***9.8*** $\boldsymbol{Mm^3/a}$

The groundwater allocation is 35.9 % of the recharge potential.

The groundwater Reserve % of recharge potential is similar to that of the Rawsonville area (~65%).

Groundwater allocation and current use estimate $\boldsymbol{(Mm^3)}$

Month	Natural Flow (incremental)	Baseflow	G/w contrib	IFR	usable g/w contribution
OCT	12.11	8.17	2.66	3.29	0.00
NOV	8.90	6.16	2.09	2.76	0.00
DEC	4.27	3.73	1.60	1.72	0.00
JAN	2.49	1.98	1.10	1.40	0.00
FEB	3.25	1.39	0.75	1.48	0.00
MAR	3.28	1.61	0.63	1.30	0.00
APR	3.85	1.70	0.62	1.03	0.00
MAY	11.41	2.75	0.68	1.30	0.00
JUN	16.82	3.60	0.93	1.64	0.00
JUL	25.39	4.87	1.38	2.53	0.00
AUG	35.72	7.63	2.23	4.15	0.00
SEP	22.64	9.92	2.83	4.12	0.00
	150.13	53.50	17.50	26.71	0.00

SUMMARY		
Recharge	27.3	*Calculated as % of mean annual rainfall x geological coefficient*
G/w Reserve	17.5	*(i.e. the groundwater contribution to baseflow)*
usable g/w contrib..	0.0	*Sum of the difference between the g/w Reserve and the incremental IFR*
G/w allocation	9.8	*Recharge - G/w Reserve + usable g/w contribution*
G/w use	6.7	*Estimated from DWAF registration of water users*
Available allocation	3.1	*Difference between g/w allocation and g/w use*

There is no IFR component in this part of the catchment. Almost 70% of the groundwater Reserve allocation is already registered. The water quality in many parts of this area poses a constraint to use for irrigation.

2.3.7 Robertson

This area comprises the catchments of the Vink, Hoops, Poesjenels and Konings Rivers.

Groundwater Reserve

QUATERNARY CATCHMENTS	RESOURCE UNIT	CATCHMENT AREA (km^2)	RECHARGE POTENTIAL (Mm^3/a)	BASEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	USEABLE GROUNDWATER CONTRIBUTION (Mm^3/a)	GROUNDWATER ALLOCATION (Mm^3/a)	GROUNDWATER ALLOCATION AS % OF RECHARGE POTENTIAL
H40 H,J,K,L	Bok/Malm*	1111	32.9	29.2	15.9	15.9	32.9	100

* Bok = Bokkeveld Group aquifers and Malm = Malmesbury Group aquifers.

The groundwater allocation for the reserve is calculated as follows:

Groundwater Allocation = ***Recharge Potential – Groundwater contribution + useable g/w contribution to baseflow***

Where

Useable g/w contribution = ***Annual g/w contribution to baseflow – Annual IFR***

According to existing information, useable g/w contribution for the Robertson area is 15.9 Mm^3/a. The groundwater allocation for the groundwater area is therefore:

Groundwater Allocation ***= 32.9 – 15.9 + 15.9*** = ***32.9 Mm^3/a***

The groundwater allocation is 100 % of the recharge potential.

Groundwater allocation and current use estimate (Mm^3)

Month	Natural Flow Incremental	Baseflow incremental	G/w contribution
OCT	6.01	3.21	1.82
NOV	5.64	2.29	1.39
DEC	3.01	2.02	1.23
JAN	2.63	1.25	0.95
FEB	2.74	1.34	0.92
MAR	2.34	1.51	0.98
APR	7.02	1.35	0.92
MAY	10.10	2.40	1.22
JUN	7.31	3.14	1.50
JUL	7.57	2.68	1.40
AUG	15.05	3.22	1.60
SEP	10.11	4.78	2.01
	79.54	29.18	15.94

SUMMARY		
Recharge	32.9	*Calculated as % of mean annual rainfall x geological coefficient*
G/w Reserve	15.9	*(i.e. the groundwater contribution to baseflow)*
usable g/w contrib.	0.0	*Sum of the difference between the g/w Reserve and the incremental IFR*
G/w allocation	17.0	*Recharge - G/w Reserve + usable g/w contribution*
G/w use	4.1	*Estimated from DWAF registration of water users*
Available allocation	12.9	*Difference between g/w allocation and g/w use*

Since the IFR volume at IFR site 3 (upstream) is almost 80 Mm^3/a greater than at gauging station H5H004 (downstream), the total groundwater Reserve could arguably also be available for abstraction. Current use is 24% of the Reserve allocation, however, groundwater quality poses a constraint to development of the resource for irrigation in most valley areas.

2.3.8 Kogmanskloof

Comprising the Keisers and Kinga River catchments as well as quaternary catchment H30E situated south-west of the Langeberg Mountains.

Groundwater Reserve

QUATERNARY CATCHMENTS	RESOURCE UNIT	CATCHMENT AREA (km^2)	RECHARGE POTENTIAL (Mm^3/a)	BASEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	USEABLE GROUNDWATER CONTRIBUTION (Mm^3/a)	GROUNDWATER ALLOCATION (Mm^3/a)	GROUNDWATER ALLOCATION AS % OF RECHARGE POTENTIAL
H30A,B,C,D,E	TMG/Bok *	1212	33.4	9.4	3.7	2.79	32.49	97.2

* TMG = Table Mountain Group; Bok = Bokkeveld Group aquifers.

The groundwater allocation for the reserve is calculated as follows:

Groundwater Allocation = ***Recharge Potential – Groundwater contribution + useable g/w contribution to baseflow***

Where

Useable g/w contribution = ***Annual g/w contribution to baseflow – Annual IFR***

According to existing information, useable g/w contribution for the Kogmanskloof area is 2.79 Mm^3/a. The groundwater allocation for the groundwater area is therefore:

Groundwater Allocation ***= 33.4 – 3.7 + 2.79*** = ***32.49*** Mm^3/a

The groundwater allocation is 97.2 % of the recharge potential.

Groundwater allocation and current use estimate (Mm^3***)***

Month	Natural Flow Mm^3/a	Baseflow Mm^3/a	G/w contrib. Mm^3/a	IFR Maintenance low flow	usable g/w contribution
OCT	2.41	0.86	0.38	0.14	0.24
NOV	2.15	0.61	0.26	0.12	0.14
DEC	0.85	0.54	0.20	0.03	0.17
JAN	0.68	0.15	0.10	0.01	0.09
FEB	0.55	0.23	0.10	0.01	0.09
MAR	0.70	0.27	0.15	0.01	0.14
APR	3.55	0.28	0.16	0.04	0.12
MAY	5.38	1.05	0.29	0.07	0.22
JUN	3.13	1.61	0.45	0.05	0.40
JUL	3.11	0.84	0.40	0.07	0.33
AUG	5.74	1.31	0.63	0.17	0.46
SEP	3.76	1.61	0.55	0.14	0.41
	32.01	9.35	3.65	0.86	2.79

SUMMARY		
Recharge	33.4	*Calculated as % of mean annual rainfall x geological coefficient*
G/w Reserve	3.7	*(i.e. the groundwater contribution to baseflow)*
usable g/w contrib..	2.8	*Sum of the difference between the g/w Reserve and the incremental IFR*
G/w allocation	32.5	*Recharge - G/w Reserve + usable g/w contribution*
G/w use	14.3	*Estimated from DWAF registration of water users*
Available allocation	18.2	*Difference between g/w allocation and g/w use*

Groundwater use (or registration) in catchment H300 is almost 45% of the groundwater allocation. The low groundwater contribution to baseflow implies that most of the recharge potential is available for abstraction.

2.3.9 Ashton to Swellendam

This area comprises the quaternary catchments H50A and B (Bonnievale) and H70A and B (Swellendam). Separation of the flow series for IFR site 4 was carried out after separation of the flows for Buffeljags, Kogmans, Riviersonderend and gauge H5H004.

Groundwater Reserve

QUATERNARY CATCHMENTS	RESOURCE UNIT	CATCHMENT AREA (km^2)	RECHARGE POTENTIAL (Mm^3/a)	BASEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	USEABLE GROUNDWATER CONTRIBUTION (Mm^3/a)	GROUNDWATER ALLOCATION (Mm^3/a)	GROUNDWATER ALLOCATION AS % OF RECHARGE POTENTIAL
H50A,B H70A,B	TMG/Bok *	1077	26.5	36.7	36.7	3.33	> 26.5	> 100

* TMG = Table Mountain Group; Bok = Bokkeveld Group aquifers and Malm = Malmesbury Group aquifers.

The groundwater allocation for the reserve is calculated as follows:

Groundwater Allocation = ***Recharge Potential – Groundwater contribution + useable g/w contribution to baseflow***

Where

Useable g/w contribution = ***Annual g/w contribution to baseflow – Annual IFR***

According to existing information, useable g/w contribution for the Ashton to Swellendam area is 3.33 Mm^3/a. Based on the fact that the groundwater component of baseflow exceeds the recharge potential, the groundwater allocation for this area exceeds is more than 26.5 Mm^3/a, which is more than 100%.

The groundwater contribution to baseflow is greater than the recharge potential implying that one or both estimates are incorrect. The recharge estimate is not significantly different to the harvest potential (see Table 3) and the error may therefore be in the flow figures.

Groundwater allocation and current use estimate (Mm^3)

Month	Natural Flow incremental	Baseflow incr. baseflow	G/w contrib	IFR Site 4	HSH04	Kogel-mans	Buffel	Sonderend	IFR increment	usable g/w contrib.
OCT	34.39	13.59	4.25	46.18	12.09	0.14	4.782	3.543	25.63	0.00
NOV	24.47	11.68	4.06	29.00	8.17	0.12	4.797	2.514	13.40	0.00
DEC	11.64	9.18	3.75	12.10	5.32	0.03	3.192	1.152	2.41	1.34
JAN	8.48	4.37	2.96	15.27	5.28	0.01	3.06	0.86	6.06	0.00
FEB	6.21	3.45	1.99	8.50	5.24	0.01	3.711	0.855	0.00	1.99
MAR	6.35	3.90	2.13	10.70	4.37	0.01	2.931	0.635	2.76	0.00
APR	22.21	3.39	1.88	14.80	5.82	0.04	2.272	1.212	5.45	0.00
MAY	37.23	5.23	2.05	18.20	7.73	0.07	1.117	1.391	7.90	0.00
JUN	43.71	8.16	2.52	35.80	12.60	0.05	0.951	2.382	19.81	0.00
JUL	57.59	10.72	3.04	58.70	16.29	0.07	1.314	2.897	38.14	0.00
AUG	61.72	21.14	3.80	83.00	20.73	0.17	2.404	3.851	55.84	0.00
SEP	39.55	14.73	4.31	67.40	17.12	0.14	3.366	3.886	42.89	0.00
	353.64	109.56	36.74	399.65	120.75	0.86	33.90	25.18	220.28	3.33

SUMMARY		
Recharge	26.50	*Calculated as % of mean annual rainfall x geological coefficient*
G/w Reserve	36.70	*(i.e. the groundwater contribution to baseflow)*
usable g/w contrib..	3.33	*Sum of the difference between the g/w Reserve and the incremental IFR*
G/w allocation	3.33	*Recharge - G/w Reserve + usable g/w contribution*
G/w use	0.90	*Estimated from DWAF registration of water users*
Available allocation	2.43	*Difference between g/w allocation and g/w use*

There is apparently an available allocation of 2,4 Mm^3/a from the usable groundwater contribution to river flow but this may be spurious. Groundwater use for irrigation is in any case limited because of poor quality.

2.3.10 Buffeljags

This is a particularly mountainous area where surface water, at least, below the Langeberg Mountains meet most water needs. In Barrydale, north of the Langeberg, there is considerable reliance placed on groundwater and approximately 2,5 Mm^3/a is used.

Groundwater Reserve

QUATERNARY CATCHMENTS	RESOURCE UNIT	CATCHMENT AREA (km^2)	RECHARGE POTENTIAL (Mm^3/a)	BASEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	USEABLE GROUNDWATER CONTRIBUTION (Mm^3/a)	GROUNDWATER ALLOCATION (Mm^3/a)	GROUNDWATER ALLOCATION AS % OF RECHARGE POTENTIAL
70 D,E,F	TMG/Bok *	737	30	62.6	25.3	2.6	7.3	24

* TMG = Table Mountain Group; Bok = Bokkeveld Group aquifers.

The groundwater allocation for the reserve is calculated as follows:

Groundwater Allocation = ***Recharge Potential – Groundwater contribution + useable g/w contribution to baseflow***

Where

Useable g/w contribution = ***Annual g/w contribution to baseflow – Annual IFR***

According to existing information, useable g/w contribution for the Buffeljags area is 2.6 Mm^3/a. The groundwater allocation for the groundwater area is therefore:

Groundwater Allocation ***= 30 – 25.3 + 2.6*** = ***7.3 Mm^3/a***

The groundwater allocation is 24 % of the recharge potential.

Groundwater allocation and current use estimate (Mm^3)

Month	Natural Flow	Baseflow	G/w contrib.	IFR low flow	usable g/w contribution
OCT	13.45	6.14	2.17	4.78	0.00
NOV	13.49	7.25	2.30	4.80	0.00
DEC	8.81	6.10	2.54	3.19	0.00
JAN	6.92	4.20	2.26	3.06	0.00
FEB	7.65	4.15	2.06	3.71	0.00
MAR	8.78	4.49	1.99	2.93	0.00
APR	10.21	4.62	1.95	2.27	0.00
MAY	9.20	4.64	2.06	1.12	0.94
JUN	6.20	4.76	2.08	0.95	1.13
JUL	8.00	4.60	1.84	1.31	0.53
AUG	13.03	5.09	1.98	2.40	0.00
SEP	12.42	6.51	2.03	3.37	0.00
	118.15	62.55	25.27	33.90	2.60

SUMMARY		
Recharge	30	*Calculated as % of mean annual rainfall x geological coefficient*
G/w Reserve	25.3	*(i.e. the groundwater contribution to baseflow)*
usable g/w contrib..	2.60	*Sum of the difference between the g/w Reserve and the incremental IFR*
G/w allocation	7.30	*Recharge - G/w Reserve + usable g/w contribution*
G/w use	2.50	*Estimated from DWAF registration of water users*
Available allocation	4.80	*Difference between g/w allocation and g/w use*

The high groundwater Reserve implies a limited groundwater allocation (7,3 Mm^3/a) of which approximately 66% is still available for allocation.

2.3.11 Riviersonderend

Groundwater Reserve

QUATERNARY CATCHMENTS	RESOURCE UNIT	CATCHMENT AREA (km^2)	RECHARGE POTENTIAL (Mm^3/a)	BASEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	USEABLE GROUNDWATER CONTRIBUTION (Mm^3/a)	GROUNDWATER ALLOCATION (Mm^3/a)	GROUNDWATER ALLOCATION AS % OF RECHARGE POTENTIAL
60 A-L	TMG/Bok *	2251	139.2	42.4	18.9	2.16	122.46	87.9

* TMG = Table Mountain Group; Bok = Bokkeveld Group aquifers.

The groundwater allocation for the reserve is calculated as follows:

Groundwater Allocation = ***Recharge Potential – Groundwater contribution + useable g/w contribution to baseflow***

Where

Useable g/w contribution = ***Annual g/w contribution to baseflow – Annual IFR***

According to existing information, useable g/w contribution for the Riviersonderend area is 2.79 Mm^3/a. The groundwater allocation for the groundwater area is therefore:

Groundwater Allocation = 139.2 – 18.9 + 2.16 = 122.46 Mm^3/a

The groundwater allocation is 87.9 % of the recharge potential.

Groundwater allocation and current use estimate (Mm^3)

Month	Natural Flow	Baseflow	G/w contrib.	IFR Low maintenance	usable g/w contribution
OCT	38.65	5.98	2.17	3.54	0.00
NOV	27.04	4.64	1.97	2.51	0.00
DEC	10.93	2.43	1.74	1.15	0.59
JAN	6.16	1.87	1.46	0.86	0.60
FEB	5.58	1.50	1.30	0.86	0.45
MAR	5.41	1.17	1.11	0.64	0.48
APR	19.63	1.56	1.25	1.21	0.04
MAY	45.11	1.64	1.27	1.39	0.00
JUN	67.54	2.40	1.28	2.38	0.00
JUL	73.71	4.71	1.48	2.90	0.00
AUG	83.86	5.61	1.78	3.85	0.00
SEP	56.29	8.91	2.11	3.89	0.00
	439.92	42.44	18.92	25.18	2.16

SUMMARY		
Recharge	139.2	*Calculated as % of mean annual rainfall x geological coefficient*
G/w Reserve	18.9	*(i.e. the groundwater contribution to baseflow)*
usable g/w contrib..	2.2	*Sum of the difference between the g/w Reserve and the incremental IFR*
G/w allocation	122.5	*Recharge - G/w Reserve + usable g/w contribution*
G/w use	1.9	*Estimated from DWAF registration of water users*
Available allocation	120.6	*Difference between g/w allocation and g/w use*

Around 60% of recharge occurs in the Villiersdorp region (H60A, B, C) where water quality is acceptable (<70 mS/m) for irrigation of vines and fruit trees. There is limited groundwater use because of sufficient surface water in most areas. In the middle and lower parts of the Riviersonderend basin, water quality is poor (>300 mS/m) and limits the use of groundwater for irrigation.

2.3.12 Lower Breede

Groundwater Reserve

QUATERNARY CATCHMENTS	RESOURCE UNIT	CATCHMENT AREA (km^2)	RECHARGE POTENTIAL (Mm^3/a)	BASEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	USEABLE GROUNDWATER CONTRIBUTION (Mm^3/a)	GROUNDWATER ALLOCATION (Mm^3/a)	GROUNDWATER ALLOCATION AS % OF RECHARGE POTENTIAL
H70G,H,J	Bok *	1606	25.3	26	9.9	9.89	25.29	99.9

* Bok = Bokkeveld Group aquifers.

Groundwater contribution to baseflow is approximately 10% of total run-off in the Lower Breede

The groundwater allocation for the reserve is calculated as follows:

Groundwater Allocation = ***Recharge Potential – Groundwater contribution + useable g/w contribution to baseflow***

Where

Useable g/w contribution = ***Annual g/w contribution to baseflow – Annual IFR***

According to existing information, useable g/w contribution for the Lower Breede area is 9.89 Mm^3/a. The groundwater allocation for the groundwater area is therefore:

Groundwater Allocation ***= 25.3 – 9.9 + 9.89*** = ***25.29*** Mm^3/a

The groundwater allocation is 99.9 % of the recharge potential.

Groundwater allocation and current use estimate (Mm^3)

Month	Natural Flow	Baseflow	G/w contribution to baseflow
OCT	131.73	2.71	1.04
NOV	96.10	2.47	0.90
DEC	45.79	1.76	0.78
JAN	33.44	0.95	0.57
FEB	33.28	1.22	0.57
MAR	34.99	1.45	0.65
APR	83.55	1.53	0.55
MAY	184.41	2.99	1.01
JUN	266.63	2.32	1.01
JUL	314.55	2.39	0.85
AUG	363.54	2.73	0.86
SEP	214.80	3.50	1.11
	1802.84	26.02	9.89

SUMMARY		
Recharge	25.3	*Calculated as % of mean annual rainfall x geological coefficient*
G/w Reserve	9.9	*(i.e. the groundwater contribution to baseflow)*
usable g/w contrib..	0.0	*Sum of the difference between the g/w Reserve and the incremental IFR*
G/w allocation	15.4	*Recharge - G/w Reserve + usable g/w contribution*
G/w use	0.0	*Estimated from DWAF registration of water users*
Available allocation	15.4	*Difference between g/w allocation and g/w use*

Although there is a considerable allocation still available (~15 Mm^3/a) for abstraction, poor water quality (>300 mS/m) poses a constraint on groundwater utilisation. This is also indicated by there being no registered groundwater users in the Lower Breede. Limited use is made of groundwater for stockwatering. The IFR at IFR Site 4 is greater than at the estuary implying that all recharge could arguably be available for abstraction.

2.3.13 Witsand and the Potberg (H70K)

A reserve determination is not possible for this quaternary catchment (H70K) as there are no flow series available. The estimated recharge for the catchment is 5,7 Mm^3/a. There are two significant aquifers in the catchment: the Witsand alluvial aquifer and the TMG aquifers of the Potberg mountain range.

Use is made of the Witsand alluvial aquifer primarily in summer by holiday-makers. Groundwater quality is generally good (<70 mS/m) but the aquifer is sensitive to pollution from inappropriate waste disposal practices and saline intrusion from over-abstraction. An allocation of approximately 2,5 Mm^3/a is recommended for alluvial aquifer with the constraints that boreholes not be situated within 100 m of the hide tide level on the shoreline or estuary and drawdown levels do not exceed mean annual sea level. Groundwater probably plays a role in supplying fresh water to some aquatic species and plants on the peripheral areas of the estuary, however, this is difficult to establish, let alone provide the volume of groundwater to sustain this function.

The Potberg is likely to have groundwater sensitive springs or wetlands and therefore a preliminary groundwater allocation of 2 Mm^3 is recommended with the remaining recharge (1,2 Mm^3/a) to the catchment allotted to ecological requirements.

2.4 SUMMARY OF RAPID LEVEL RESERVE DETERMINATION

The Rapid Level Reserve Determinations for the Breede WMA are summarised in the following table.

TABLE 3 : SUMMARY OF RAPID RESERVE DETERMINATIONS, GROUNDWATER ALLOCATIONS AND USE

QUATERNARY CATCHMENT	RESOURCE UNIT	AREA (km^2)	RECHARGE POTENTIAL (Mm^3/a)	HARVEST POTENTIAL (HAUPT)[1]	BASEFLOW[2] (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	GROUNDWATER ALLOCATION	GROUNDWATER ALLOCATION AS % OF RECHARGE POTENTIAL	REGISTERED GW USE	REMAINING ALLOCATION
H10A, B, C	Ceres	659	31.6	32.4	51.8	17.3	14.30	45	18.5	0.0
H10D, F	Wolseley	348	32.7	37	59.4	24.7	12.16	37	7.5	4.7
H10E, G, H,J ,K ,L	Rawsonville	1052	177.4	107	182.4	115	85.96	48	24.8	61.2
H200A to H	Hex	837	54.3	49.7	41.2	16.5	45.40	84	20.5	24.9
H40A, B, C	Keerom, Nuy/Nonna	700	27.2	36.7	5.4	4.7	26.57	98	3.2	23.4
H40D, E, F	Moordkuil	812	27.3	28.7	43.5	17.5	9.80	36	6.7	3.1
H40G, H J, K, L	Robertson	1111	32.9	43.6	29.2	15.9	32.90	100	4.1	28.8
H30A to E	Kogmans	1212	33.4	47.2	9.4	3.7	32.49	97	14.3	18.2
H50A, B, H70A, B	Bonnievale to Swellendam	1077	26.5	27.5	94	36.7	(3.3)	>100	0.9	2.4
H70C, D, E, F	Buffeljags	737	30.0	31.1	62.6	25.3	7.30	24	2.5	4.8
H60A to L	Riviersonderend	2251	139.2	96.7	42.4	18.9	122.46	88	1.9	120.6
H70G, H, J	Lower Breede	1606	25.3	23.5	26	9.9	25.29	100	0	25.3

1. Harvest Potential (Haupt 1999)
2. Baseflow (i.e. interflow plus the groundwater contribution to baseflow)

3. INTERMEDIATE LEVEL RESERVE DETERMINATIONS

3.1 INTRODUCTION

Intermediate level Reserve Determinations have been conducted in the H1 (excluding Ceres basin) and the lower part of H2 (Hex catchment) secondary catchments, and supersede rapid level determinations for Wolseley and Rawsonville. In a parallel study, an intermediate groundwater Reserve determination was carried out by Parsons & Associates (December, 2001) for the Hex River Valley, and the results of this study will supersede the rapid level determination for the Hex River Valley.

3.1.1 Methodology

The Intermediate Reserve Determination (IRD) methodology is a seven step procedure (DWAF, 1999). The first two steps require delineation of geographical boundaries of the significant water resource and delineation of homogenous response units and geohydrological region types. This is followed by assessment of reference conditions, description of current status, setting the desired management class, quantification of the groundwater allocation and recommendations for monitoring and review. The only way to check the validity of IRD estimates is to monitor the response of systems to natural and anthropogenic influences and review the estimates on a regular basis (e.g. every 3 to 5 years).

3.1.2 Assumptions of the Methodology

Depth of Groundwater

A fundamental assumption of the IRD method is that if groundwater levels remain relatively constant and do not decline over the long term, the ability of groundwater systems to sustain the ecological Reserve remains intact. In other words, it is not the storage in the aquifer that determines the ability of groundwater to supply aquatic ecosystems but the groundwater 'depth' or 'head' relative to the streambed or groundwater dependent ecosystem. While this may be seen as a constraint to groundwater abstraction from alluvial aquifers that have a high degree of interaction with surface water, this may not necessarily be the case for deep-seated fractured rock aquifers where the degree of interaction with surface streams is limited. Provided the cone of depression induced by pumping does not extend to a streambed or riparian zone, groundwater abstraction should not significantly affect surface flows.

Seasonal and Temporal Variation

The phrases 'relatively constant' and 'the long term' are critical to understanding the role of groundwater in the concept of the Reserve. Groundwater levels fluctuate seasonally and over a longer period associated with natural drought cycles. The extent to which groundwater levels fluctuate depends primarily on the rate at which abstraction occurs and the hydraulic properties in the immediate vicinity of the borehole. For example, a borehole abstracting from an alluvial aquifer in a floodplain may show a small fluctuation in groundwater levels compared to a borehole situated in a fractured aquifer in a mountainous area.

Historical rainfall patterns from 1920 to 1998 from a number of gauging stations in the Breede River catchment show a cyclical pattern of drought to wet periods with a return frequency of from 7 to 10 years. This natural variation can result in groundwater levels declining in some aquifers in dry years but recovering in years of above average rainfall. Some aquifers show little evidence of water level decline, even in dry periods. For example, in the Hex Valley, groundwater levels do not appear to decline in years of below average rainfall in boreholes close to recharge areas (i.e. the Hex Mountains) whereas a decline in groundwater levels (and quality) is seen in boreholes abstracting from aquifers more distant from recharge areas. Recognising these influences and interpreting groundwater hydrographs to differentiate between natural and man-made causes of falling groundwater levels and reduced baseflow is an important outcome of any monitoring programme. A brief description of the IRD methodology and approach used in this report is provided in the following section.

3.1.3 Delineation of Boundaries

Intermediate Reserve Determinations have been carried out for two water resource areas in the Breede River catchment. Water resource area 1 extends from Wolseley to the Brandvlei Dam (Figure 4) and water resource area 2 from Worcester to the eastern boundary of quaternary catchment H40C (Figure 6).

Homogenous response units

Homogenous response units have similar characteristics based on geology, climate and topography. In the context of the groundwater component of the Reserve, homogenous response units relate specifically to geohydrological characteristics. The setting of boundaries is intended as an iterative process based on knowledge derived from monitoring and new information from development of the water resource. The setting of homogenous response units is based on the conceptual understanding of the groundwater system (Figure 5 and Table 4) in the upper Breede Basin and three units are recognised:

- Aquifers associated with the TMG, i.e. mountainous recharge unit (Unit A);
- Unconfined alluvial aquifers in the Breede River valley (Unit B);
- Fractured rock aquifers of the hillslopes and valley of the upper Breede Basin (Unit C).

Geohydrological region typing of response units

Division of homogenous response units into geohydrological units is based on the significant hydrological and environmental function of each geohydrological region type in the catchments. In other words, geohydrological region typing identifies components within homogenous response units that play a unique role in the hydrological and ecological functioning of that unit. Geohydrological region types are grouped according to the chief role or function, i.e. maintaining system integrity, (e.g. terrestrial vegetation) discharge integrity (e.g. water supplies) or ecological integrity (e.g. flow to streams).

3.1.4 Reference Conditions

Reference conditions may only be described qualitatively since records from pre-water resource development times are not available. Hydrograph separation of the naturalised monthly run-off sequences may be used as an indicator of the groundwater contribution to basin yield (baseflows) prior to water resource development whereas gauged flows are likely to be indicative of anthropogenic influences. The determination of the groundwater contribution to baseflow (and therefore river flow) has been carried out by hydrograph separation of the naturalised monthly run-off sequences.

3.1.5 Present Status

Agricultural developments and associated infrastructure (roads, canals, drainage ditches) have undoubtedly had some impact on the hydrology of the Breede Basin. The impact on aquifers is more difficult to determine, however, low flow records in the Hex River at the Sesbek weir (upstream of De Wet) for the past 70 years suggest a decline in baseflow with increased water use in the Hex Valley (Papini *et al,* 2001). This is probably not attributable to groundwater abstraction alone as the interception of run-off by dams has undoubtedly also reduced baseflow. The alluvial aquifers are considered the most impacted in terms of declines in both groundwater level and quality. However, evidence from the limited records and reports that are available suggests that most aquifers in the Breede Basin are utilised in a sustainable manner with the possible exception of certain drought prone areas in the Hex River Valley.

Hydrological changes indicated from aerial photographs show that river courses used to be wider and the main channel of the Breede River changed regularly (i.e. a more typical braided river system) from flood events. Construction of dams and diversion weirs has reduced not only the volume in streams but also the intensity of flood events, which has reduced the frequency of channel migration. To control flood events, excavating embankments in some areas confined stream channels. Agricultural areas with high water tables had ditches dug to drain the soils and assist with flushing of salts resulting from irrigation of vineyards and orchards. In some areas of alluvium, shallow groundwater levels have been permanently reduced water levels as a result of drainage ditches that collect poor quality irrigation return flows. In many undeveloped parts of the Basin the current status is unchanged from the reference conditions.

3.1.6 Management Class

The management class is used to guide the protection and management of a particular unit or area. The management class is used to set the frequency of the IRD review and to limit groundwater abstraction (DWAF, 1999). The review is based on monitored water level and quality data. Where the present status category is E or F (highly impacted), the desired management class would be C. The required action in this case would be to institute monitoring, initiate a comprehensive reserve determination and review within 1 year.

3.1.7 Quantification of the Groundwater Allocation

Average annual recharge within a geohydrological response unit forms the basis of setting the groundwater allocation. The recharge estimation method is left to the discretion of the geohydrologist undertaking the Reserve determination. The groundwater allocation is determined by subtracting the low maintenance baseflow (in-stream flow requirements) and basic human needs volumes from the recharge estimate. In this report the recharge estimation method is based on a % of mean annual precipitation (MAP) multiplied by a geological coefficient (Appendix A). No adjustment was made for basic human needs as these comprise an insignificant percentage of the groundwater allocation.

The allocation of a low maintenance baseflow to the geohydrological response units is problematic because the IFR volume refers to a specific point (usually the bottom) in a catchment. The low maintenance baseflow must be apportioned to each geohydrological unit in order to determine the groundwater allocation in that unit. In this report the low maintenance baseflow for each geohydrological unit was calculated on the basis of the recharge volume per geohydrological unit, i.e. by dividing the recharge in the geohydrological unit by the total recharge in the water resource area unit and multiplying by the total IFR.

The monthly groundwater contribution to baseflow (estimated by hydrograph separation) often exceeds the monthly low maintenance baseflow implying that this difference may be available for abstraction from boreholes. The monthly assurance values for the groundwater contribution to baseflow are provided in Appendix B. The volume representing the difference between the monthly groundwater contribution to baseflow and the monthly IFR is termed the 'usable groundwater contribution to river flow' and is added to the groundwater allocation (Table 4). The usable groundwater contribution is usually less than 20% of the recharge potential and in some catchments there is no usable groundwater contribution. This groundwater should be utilised in the months that it is available (i.e. decreasingly from September to January) in order not to affect the IFR. This may, in places, require the use of groundwater earlier and surface water (e.g. from dams) later in the irrigation season.

TABLE 4 : CALCULATION OF THE USABLE GROUNDWATER CONTRIBUTION (Mm^3) IN WATER RESOURCE AREA 1

Month	Natural Flow	Baseflow	G/w contribution to baseflow	IFR	usable g/w contribution
OCT	23.00	22.95	17.99	10.38	7.61
NOV	10.48	10.48	10.48	6.36	4.13
DEC	5.69	5.69	5.69	4.49	1.20
JAN	5.89	4.33	4.33	4.97	0.00
FEB	5.01	4.71	3.90	4.50	0.00
MAR	4.42	4.42	3.27	3.88	0.00
APR	13.92	9.12	3.22	5.40	0.00
MAY	52.44	12.24	3.74	7.72	0.00
JUN	99.66	17.46	6.80	13.84	0.00
JUL	119.80	24.45	12.33	18.26	0.00
AUG	115.47	36.00	17.71	21.70	0.00
SEP	62.99	29.84	20.62	16.10	4.52
	518.79	**182.44**	**110.09**	**117.58**	**17.45**

1) incremental IFR=H100–H1H006.

2) usable g/w contribution=g/w contribution to baseflow–incremental IFR.

Resource quality objectives

Resource quality objectives are set to ensure that the integrity of the Reserve is maintained and to provide management guidelines and performance specifications. There is no formal process in place to define Resource Quality Objectives for groundwater but important actions to meet objectives (be they water quality or a groundwater level adjacent to a river) include drawdown limitations, restriction on pumping close to rivers and springs and protection zoning.

3.1.8 Monitoring and Review

A hydrocensus of boreholes in water resource units 1 and 2 (Appendix C) indicates that there are very few boreholes that could be used for monitoring regional groundwater levels as most boreholes are used for irrigation. There is a need to establish dedicated monitoring boreholes in proximity of rivers and streams in areas where significant abstraction is taking place. A number of boreholes abstracting significant volumes of groundwater need to be equipped with piezometer tubes to measure groundwater levels. Site specific rainfall data is required and, together with gauged stream flow data, groundwater level and abstraction data should be used in improving the recharge estimates of the water resource areas.

3.2 WATER RESOURCE AREA 1 (WOLSELEY TO BRANDVLEI)

3.2.1 Introduction

The upper Breede River catchment was identified for IRD because of significant volumes of groundwater used for irrigation (particularly in the Rawsonville area) and the potential for additional abstraction. Although the basic area of an IRD assessment is the quaternary catchment this is not appropriate in the case of the upper Breede because of the extent of the alluvial deposits, (the most utilised aquifer in Area 1) and cannot easily be sub-divided on a geohydrological basis. The area for the IRD therefore commences at the base of Michell's Pass (near Wolseley) and terminates at the Brandvlei Dam (Figure 4).

3.2.2 Delineation of Homogenous Response Units (HRU) and Geohydrological Region Types (GRT)

Homogenous response units are based on geology and current understanding of the geohydrology of the area. The characteristics of the HRU are summarised in Table 5. Figure 5 is a cross-section of the study area from southwest to northeast and indicates the HRU and groundwater flow directions toward the Breede River and between units.

TABLE 5 : CHARACTERISTICS OF HOMOGENOUS RESPONSE UNITS (HRU)

HOMOGENOUS RESPONSE UNIT	**A**	**B**	**C**
Description	Mountain Recharge Zones	Alluvial deposits (>6m)	Lowland and hill-slope fractured rock aquifers
Geology	Quartzitic sandstone	Sand and boulders	Shale, conglomerate and minor sandstone
Aquifer type	Consolidated (fractured). Unconfined to semi-confined	Unconsolidated Unconfined	Consolidated (fractured). Confined.
Transmissivity (T) and Storage (S)	High T; low to moderate S	High T and S	Low T and S
Hydraulic gradient	High	Low	Moderate
Primary recharge source and relative amount (high, moderate, low)	Rainfall (High)	Streams and rainfall (Moderate)	Rainfall (Low)
Exploitation Potential	Moderate to High	Moderate to High	Low to Moderate
Water Quality	Good (EC < 70 mS/m)	Good (EC < 70 mS/m)	Variable based on locality in basin
Vulnerability to pollution	High	High	Low
Surface/Groundwater interaction	Most recharge rapidly becomes streamflow	Large degree of interaction	Insignificant interaction
Groundwater levels	Variable (Artesian – 20m)	Shallow (1-5m)	Deep (>20m)
Examples	Waaihoekberg and Slanghoekberg	Rawsonville and De Wet adjacent to Hex River	Malmesbury shale north of the Worcester Fault

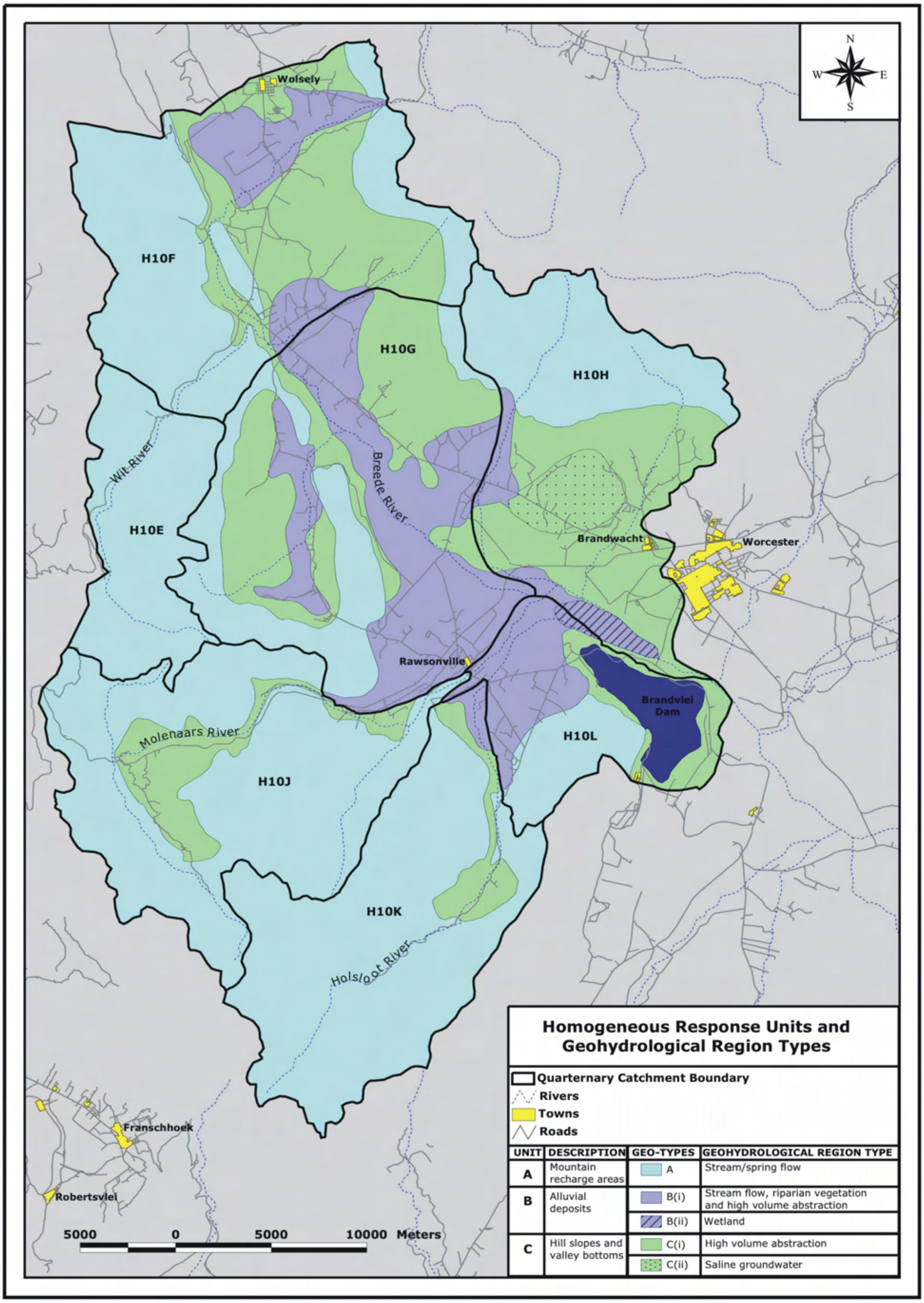


Figure 4: Water resource area 1

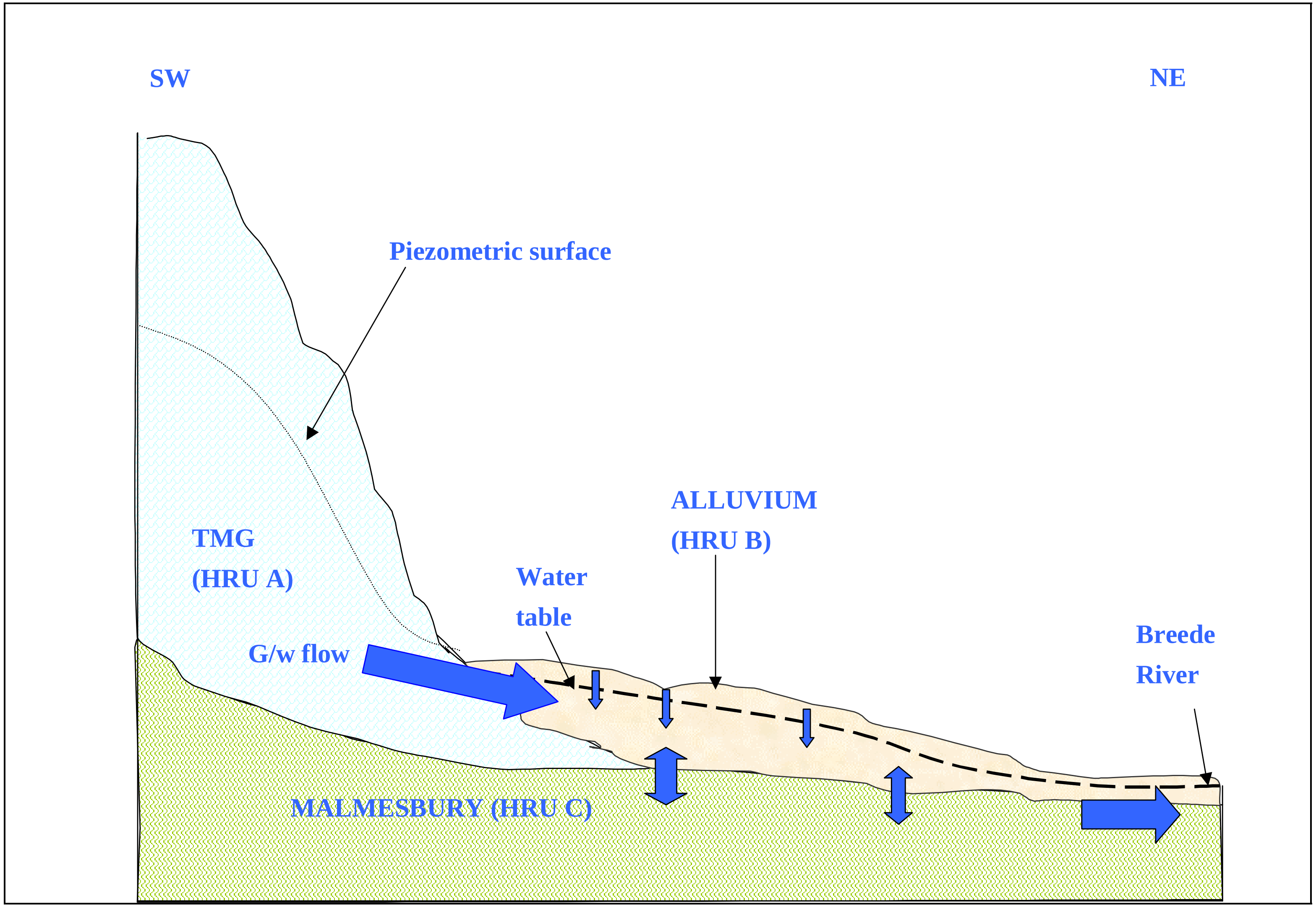


Figure 5: Cross-section through water resource area 1 from the Du Toits Mountains to the Breede River

3.2.3 Reference Conditions

The geohydrological characteristics of water resource unit 1 are provided in summary form below and a more comprehensive description provided in the groundwater assessment of the Breede Basin (GCS, 2001).

Almost 50% of the total run-off in the Breede system originates from water resource area 1. High mountain ranges border the northern, western and southern perimeters of area and comprise 725 km^2 or approximately 56% of the surface area. These mountains are comprised of quartzites and quartzitic sandstones of the Table Mountain Group which form the most important aquifers in the Western Cape. The Recharge to the TMG aquifers comprises 84% of the total recharge to water resource area 1, but these aquifers are under-utilised in area 1. However, baseflow from the TMG aquifers recharge the alluvial aquifer in the Breede River valley, from which the bulk of groundwater abstraction occurs.

Significant alluvial aquifers are present in the north (south of Wolseley), central and southern (Rawsonville) parts of water resource area 1. These comprise homogenous response unit B (Figure 4). Alluvial troughs up to 45m thick occur in the main channel areas of the Holsloot River and Molenaars River but are on average 20m to 30m thick. Abstraction from the alluvium has the potential to reduce surface flow to a greater extent than abstraction from HRUs A and C.

Fractured aquifers of the Malmesbury and Karoo Group of rocks occur on the valley sides and hillslopes, particularly east of the Breede River. These aquifers are assigned as a different homogenous response unit (HRU C) to the aquifers of the TMG (HRU A) based on different geohydrolgical characteristics (Table 4). The recharge and flow rate in aquifers of HRU C are thought to be considerably less than in HRUs A and B.

Geohydrological region types are grouped according to the chief role or function groundwater plays within a certain area, e.g. terrestrial vegetation or ecological flow to streams. Within HRU A (TMG) the geohydrological region type (GRT) provides baseflow to streams and springs. In the case of HRU B (Alluvium), the geohydrological region types are divided into B(i) – sustaining stream flow and large scale abstraction and B(ii) maintaining the Papenkuils wetland (Figure 4). The recharge to the wetland is excluded from the groundwater allocation in terms of the rules for estimating the allocation (DWAF, 1999). An area of saline groundwater is present in HRU C and has been assigned as a GRT. The recharge to this area, as with the wetland, is excluded from the groundwater allocation.

The Holsloot and Molenaars Rivers are important rivers in the south of the area. They rise in the Du Toit's Mountains and flow across the alluvial plain at Rawsonville to the Breede River. Weirs in the Holsloot and Molenaars Rivers divert winter high flows to Brandvlei Dam.

3.2.4 Current Status

A brief account of groundwater utilisation and environmental impacts is provided below.

Groundwater usage:

The TMG aquifer is not extensively used in this area because access for drilling in the rugged mountainous terrain is often impossible. Groundwater recharge becomes surface flow in the kloofs that dissect the mountains and as springs often at the base of mountains. The groundwater flow to streams in summer is also thought to recharge alluvium further downstream in the catchment. Extensive use is made of the alluvial aquifer, particularly during summer in the southern part of the area around Rawsonville. Further north, toward Wolsely, groundwater abstraction from alluvium is also significant and is frequently from shallow pits adjacent to the Breede River. Groundwater abstraction also takes place from fractured Malmesbury aquifers in the Hartbees, Jan du Toits and Wabooms River Valleys.

The overall usage made of groundwater in water resource area 1 is moderate (class C or between 20% and 40% of groundwater allocation) but with little or no negative impacts apparent. The current status for HRU A is class A (unmodified or pristine conditions) whereas for HRU B (alluvium) the overall current status is class C, however, in the Rawsonville area, is more likely to be a D (40% - 65% of groundwater allocation). The current status for HRU C is class D as approximately 65% of the groundwater allocation is registered (Table 8).

Environmental impacts

Impacts are likely to be low level and localised in most parts of the area and a B class (localised low level impacts but no negative affects apparent) is considered appropriate with a C (moderate levels of localised impacts or perceived impact on the environment) for the Rawsonville area as there is some impact from groundwater abstraction on the Papenkuils wetland and salinisation of the alluvial aquifer associated with irrigation practices.

3.2.5 Management Class

Setting the desired management class is used to set the frequency of review of the IRD and to limit groundwater abstraction when required. The current status class of C/D for GRT B(i) and D for GRT C(i) requires a desired management class of B. This means that the IRD must be reviewed within three years but there is no limitation on the groundwater allocation.

3.2.6 Groundwater Allocation

The groundwater allocation for each geohydrological region type is based on the recharge estimates. An adjustment for the in-stream-flow requirement is made by dividing the recharge for a specific GRT by the total recharge in the water resource area and multiplying by the total low maintenance baseflow volume of the IFR. This assumes a proportional contribution to the total IFR from each GRT.

The groundwater allocation in water resource area 1 is 94 Mm^3/a. The allocation from each HRU is as follows: Unit A: 80,3 Mm^3/a; Unit B: 3,3 Mm^3/a and from Unit C: 10,4 Mm^3/a (Table 6). The groundwater allocations from the Papenkuils Wetland (B(ii)) and the Saline area (C(ii)) are excluded. The level of confidence of this IRD is low to moderate as limited current on-site data was available. There is detailed hydrocensus information for this area from previous work undertaken, for example, by Whittingham, 1976 (GH 2883) and Rosewarne, 1981 (GH 3186), which needs updating.

The recharge estimate (due to infiltration from precipitation) for the alluvial aquifer in water resource unit 1 is approximately 7 Mm^3/a whereas the groundwater allocation for GRT B(i) is only 3,3 Mm^3/a. This compares with the estimated 20 Mm^3 currently abstracted annually from this aquifer type in the Rawsonville area alone. This groundwater is taken from storage in the alluvium but recharged by precipitation and streamflow, which in summer, is fed by baseflow from TMG aquifers upstream of the alluvium. The recharge estimate and IRD methodology do not allow for consideration of groundwater flowpaths or surface – groundwater interactions and how this affects recharge and therefore the groundwater allocation in specific groundwater units. These interactions are complex and often only understood after prolonged and detailed collection of hydrological information.

Given the significant surface - groundwater interaction in parts of the water resource area underlain by alluvium and that the Usable groundwater contribution of Unit A (TMG) provides baseflow that recharges the alluvium in summer, it is suggested that the groundwater allocation for the alluvial aquifer could be increased by addition of the Usable groundwater contribution of the Unit A (i.e. increased from 3,3 Mm^3 to 20,8 Mm^3 by addition of the Usable groundwater contribution of Unit A). This recommendation is not, however, included in the calculations in the data in Table 6, but is included in Table 8.

TABLE 6 : WATER RESOURCE AREA 1 IRD GROUNDWATER ASSESSMENT DATA SHEET

BOUNDARIES AND TYPING		**MANAGEMENT CLASS**		**RECHARGE**			**ADJUSTMENT**		**GROUNDWATER ALLOCATION**
Homogenous Response Units	Geohydrological Region Typing	Current Status	Desired Management Class	Area Km^2	Recharge Method	Annual Recharge (Mm^3)	Low Maintenance Baseflow Adjustment[1]	Usable groundwater contribution[2]	Groundwater Allocation
Unit A	Stream flow	A	a	640.18	%MAP x geo coefficient	179.3	116.5	17.5	80.3
Unit B	B(i) Stream flow and high volume abstraction	E	c	194.8	%MAP x geo coefficient	7.1	4.6	0.7	3.3
	B(ii) Papenkuils Wetland			6.9	%MAP x geo coefficient	0.14	0.1	Exclusion	Exclusion
Unit C	C(i) High volume abstraction	D	b	329.38	%MAP x geo coefficient	22.9	14.9	2.4	10.4
	C(ii) Saline area			18.1	%MAP x geo coefficient	0.7	0.45	Exclusion	Exclusion
TOTAL				1274	210.1		136.6	20.6	94.1

Unit A: Mountain Recharge areas (TMG);
Unit B: Alluvial deposits;
Unit C: Hill slope and valley bottom fractured rock aquifers (Bok & Karoo).

1. Baseflow adjustment = recharge_{GRT}/ $\text{recharge}_{(H100)}$ x $\text{IFR}_{(100)}$.
2. Usable groundwater contribution = recharge_{GRT} / $\text{recharge}_{(H100)}$ x Usable groundwater contribution (see Table 5).

Groundwater consumption estimates

Abstraction estimates have been based on the results of the registration (ongoing) of water users in the Breede Valley undertaken for DWAF in 2000 and 2001. The census has obtained values per quaternary catchment for areas under irrigation, total water consumption and the split between surface water and groundwater use. The census is incomplete in a number of quaternary catchments and in these cases estimated groundwater consumption has been calculated by dividing the irrigated hectares censored by DWAF by the total irrigated areas mapped from aerial photographs in the Breede Basin Study and multiplying the quotient by the current registered groundwater use per quaternary catchment. The estimates for the tertiary catchment H100 (excluding Ceres H10A, B and C) are given in Table 7.

TABLE 7: ESTIMATED GROUNDWATER USE PER QUATERNARY CATCHMENT IN WATER RESOURCE AREA 1

QUATERNARY	REGISTERED WATER USE (DWAF, 2001) (Mm^3 /a)			IRRIGATED AREA (HECTARES)		ESTIMATED GROUNDWATER USE (Mm^3/a)
	Total Volume	Surface use	Groundwater use	DWAF Registered	Breede Mapping	
H10E				0.0	33.3	
H10F	2.33	1.30	1.03	468.5	3 406.1	7.48
H10G	11.00	8.50	2.50	2 567.8	7 289.2	7.10
H10H	2.22	0.75	1.47	520.9	855.8	2.42
H10J	1.30	1.11	0.19	316.6	472.3	0.28
H10K	0.29	0.29	0	69.0	364.7	0
H10L	1.42	0.13	1.29	168.1	1 945.8	14.93
TOTAL	18.56	12.08	6.48	4 110.9	14 367.1	32.2

Groundwater available for abstraction

Groundwater available for abstraction has been calculated as the difference between the groundwater allocation (Table 6) as modified (and described in the last paragraph on page 3-11) and estimated groundwater use (Table 7). In water resource area 1, the annual volume of groundwater theoretically available for abstraction is approximately 62 Mm^3 (i.e. the groundwater allocation : 94 Mm^3 subtract the estimated current use : 32 Mm^3).

An estimate of groundwater use from each HRU in each quaternary catchment is presented in Table 8 and indicates that the current abstraction from the alluvium exceeds the groundwater allocation. This is in spite of addition of the Usable groundwater contribution for Unit A (TMG) to the groundwater allocation for Unit B (alluvial aquifer) because of the large degree of interaction between these aquifer types. The current status of Unit B is therefore F as groundwater use is in excess of 95% of the groundwater allocation. This requires that monitoring be instituted, a comprehensive reserve determination is carried out and reviewed within one year. The 63 Mm^3/a allocation for Unit A (the TMG) remains unutilised and further development of groundwater will need to take place from these aquifers if the in-stream-flow requirements are to be met.

TABLE 8 : ESTIMATE OF GROUNDWATER USE FROM EACH HRU IN EACH QUATERNARY CATCHMENT IN WATER RESOURCE AREA 1

QUATERNARY CATCHMENT	TOTAL G/W USE (Mm^3/a)	ALLUVIUM (Mm^3/a)	MALMESBURY (Mm^3/a)	TMG (Mm^3/a)
H10F	7.5	5	2.5	0
H10G	7,1	5	2.1	0
H10H	2,4	0.4	2	0
H10J	0.28	0	0.28	0
H10K	0	0	0	0
H10L	15	15	0	0
Total	32.3	25.4	6.9	0
Groundwater Allocation	94	20.8*	10.4	62.8
Remaining allocation	61.7	-4.6	3.5	62.8

* Allocation includes the addition of the Usable groundwater contribution from Unit A to Unit B

3.2.7 Monitoring and Review

A hydrocensus of boreholes from Wolesely to Worcester was undertaken with a view to identifying boreholes suitable for monitoring groundwater levels and groundwater quality. Unfortunately all of the boreholes located are currently in use and sealed at surface, making measurement of groundwater levels impossible. Pumping boreholes identified for monitoring would need to be fitted with a piezometer tube attached to the riser main pipe to allow measurement of groundwater levels. In addition to measuring the dynamic groundwater levels at pumping boreholes it is also important to know groundwater levels in the aquifer around areas of abstraction so one can assess groundwater flow directions and cones of depression associated with pumping boreholes. It is therefore important to have dedicated monitoring boreholes situated at regular distances from pumping boreholes (or wellfield) to measure the local effect on the aquifer and to assess potential impacts on surface flow. A summary of some of the boreholes identified in the field is provided in Appendix C. This does not represent all the boreholes in water resource area 1 and a hydrocensus to determine the positions of all utilised boreholes and information regarding their use is required as part of a comprehensive reserve determination.

The DWAF (Bellville Office) has monitored dedicated monitoring boreholes in the past but this activity was discontinued in the mid-1990s. A line of these monitoring boreholes, in a northeast – southwest orientation, are situated from the Jan du Toits Valley to near Goudini Spa. Another monitoring borehole is located at the primary school near Rawsonville and another in the Papenkuils wetland. Monitoring of these boreholes should be re-initiated but as part of a more extensive network that monitors groundwater levels and quality in areas where there is extensive abstraction taking place and, importantly, in proximity to surface water bodies and streams. The assessment of information from several years of monitoring will assist in determining the impact of abstraction.

The following recommendations for monitoring are made:

- Identify major groundwater users and determine positions of boreholes (GPS).

- Select 3 to 4 areas (2 to 3 in the alluvial aquifer and 1 to 2 in the fractured aquifers) that can be monitored.

- Determine proximity to streams or sensitive sites (wetlands/springs) within the monitoring areas.

- Identify existing boreholes that could be used as dedicated monitoring boreholes and, where not available, drill dedicated monitoring boreholes between abstraction boreholes and sensitive sites.

- Install data loggers to measure groundwater levels and measure salinity (EC) and potassium and phosphate quarterly.

3.3 WATER RESOURCE AREA 2 (WORCESTER TO NUY)

3.3.1 Introduction

Water resource area 2 is comprised of three quaternary catchments: H20G, H and H40C and was selected because of high estimates of groundwater use obtained in the Breede Basin Study. The Hex River Valley, where approximately 20 Mm^3 of groundwater is abstracted annually, is upstream of catchments H20G and H.

3.3.2 Delineation of Homogenous Units (HRU) and Geohydrological Region Types (GRT)

The town of Worcester is situated in the west of the water resource area 2, the Breede River is to the south and the Langeberg Mountains in the north. The homogenous response units are the same as in water resource area 1, however, unit C makes up a much larger percentage of the area than in water resource area 1. Although considered as a single water resource area because of similar geohydrological setting, the quaternary catchments through which the Hex River flows (H20G and H) are considered separately from the Nuy/Nonna catchment (H40C) in determining the groundwater allocation because of separate surface flow series for the Hex River and Nuy/Nonna River(s). The response units and geohydrological region types are indicated in Figure 6 and a typical cross-section in Figure 7.

3.3.3 Reference Conditions

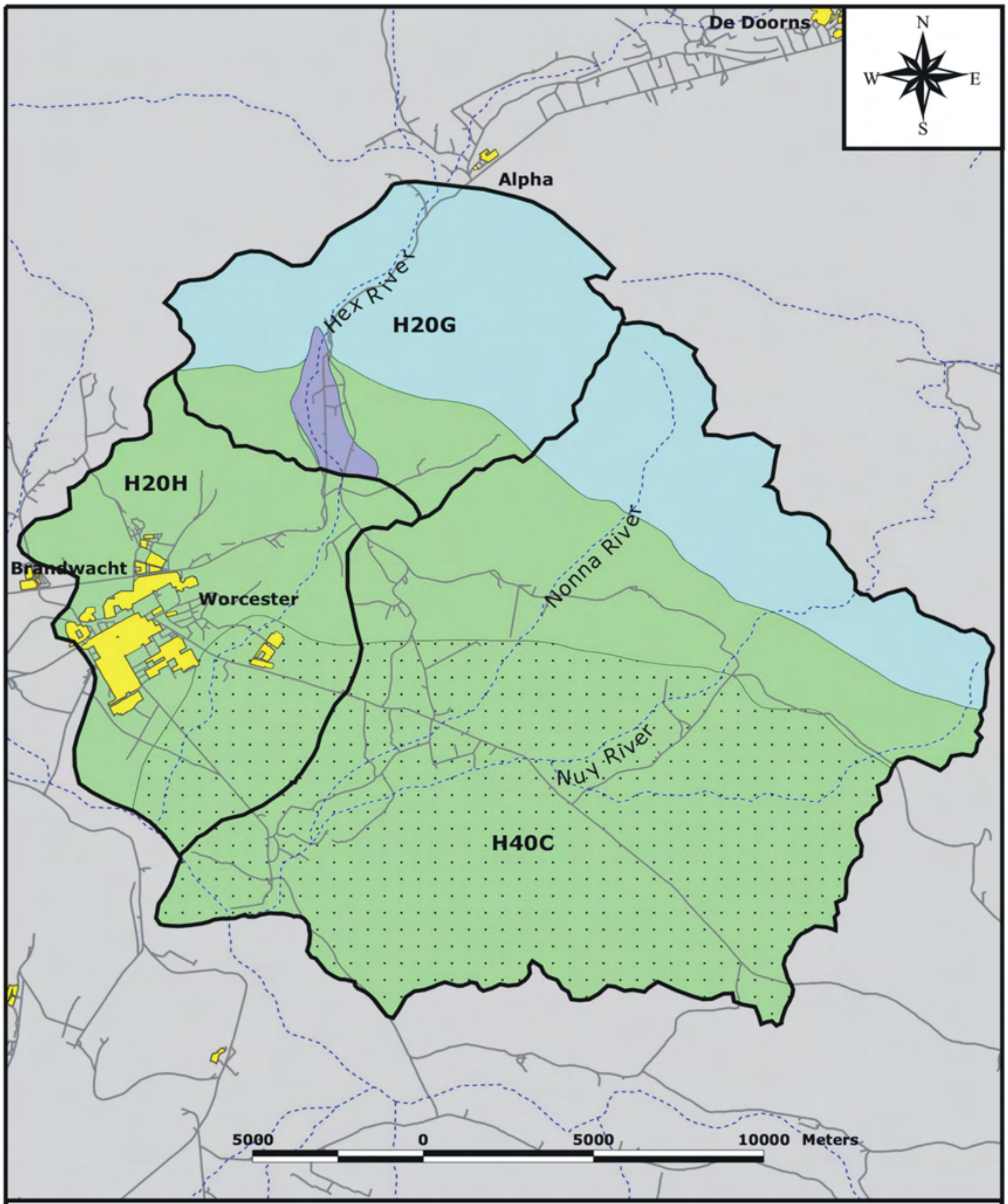
The Hex River flows through quaternary catchments H20G and H20H and the Nonna and Nuy Rivers flow through H40C. These rivers have their sources in catchments north of these quaternaries and flow into the Breede River at the southern limit of the area (Figure 6). The northern part of the area comprises the Langeberg Mountains through which the Hex, Nuy and Nonna Rivers have eroded deep kloofs. At the mouth of the Hex River kloof a significant alluvial fan occurs, formed as a result of the change in river gradient between the Langeberg Mountains and the Breede Valley. Alluvial fans associated with the Nuy and Nonna Rivers are considerably smaller than for the Hex River as they source smaller catchment areas. The Keerom Dam is situated on the Nuy River, upstream of quaternary H40C.

Most recharge in the mountains is thought to daylight as baseflow further downstream in the river and recharges alluvial aquifers, however, through flow from the TMG aquifers in the mountains to the Malmesbury aquifers in the hillslopes and valley bottoms is probably also an important recharge mechanism. The central and southern parts of the area are comprised of Malmesbury Group and Karoo Group Rocks, which are covered by thin deposits of alluvium and colluvium of the Bredasdorp Group. These deposits do not constitute significant aquifers. A major east-west fault (Worcester Fault) separates Malmesbury Group rocks north of the fault from Karoo rocks to the south. Groundwater potential from the Malmesbury Group and Karoo Group aquifers of the Breede Valley is generally poor; groundwater from Karoo Group rocks is usually too saline for irrigation in this area.

3.3.4 Current Status

Groundwater usage

Three homogenous response units (or aquifers types) are recognised: the TMG; alluvium in the De Wet area and aquifers of the Malmesbury Group, which outcrops mainly on the hillslopes of the area. The alluvial aquifer in the De Wet area is recharged primarily from baseflow in the Hex River. Groundwater levels are close to surface in the alluvial aquifer at De Wet and groundwater users abstract groundwater from shallow pits excavated several metres into the sand. Volumes pumped from these pits are, on average, between 50 000 and 75 000 m^3/a and in several instances exceed 100 000 m^3/a (or 11 ℓ/s pumping 12 hrs/day). The estimate of groundwater use in the De Wet area (H20G) is approximately 1,5 Mm^3/a (Papini *et al*, 2001).



Homogeneous Response Units and Geohydrological Region Types

▭ Quarternary Catchment Boundary
Rivers
🟨 Towns
Roads

UNIT	DESCRIPTION	GEO-TYPES	GEOHYDROLOGICAL REGION TYPE
A	Mountain recharge areas	🟦 A	Stream/spring flow
B	Alluvial deposits	🟪 B(i)	Stream flow, riparian vegetation and high volume abstraction
C	Hill slopes and valley bottoms	🟩 C(i)	High volume abstraction
		▨ C(ii)	Saline groundwater

Figure 6: Water resource area 2

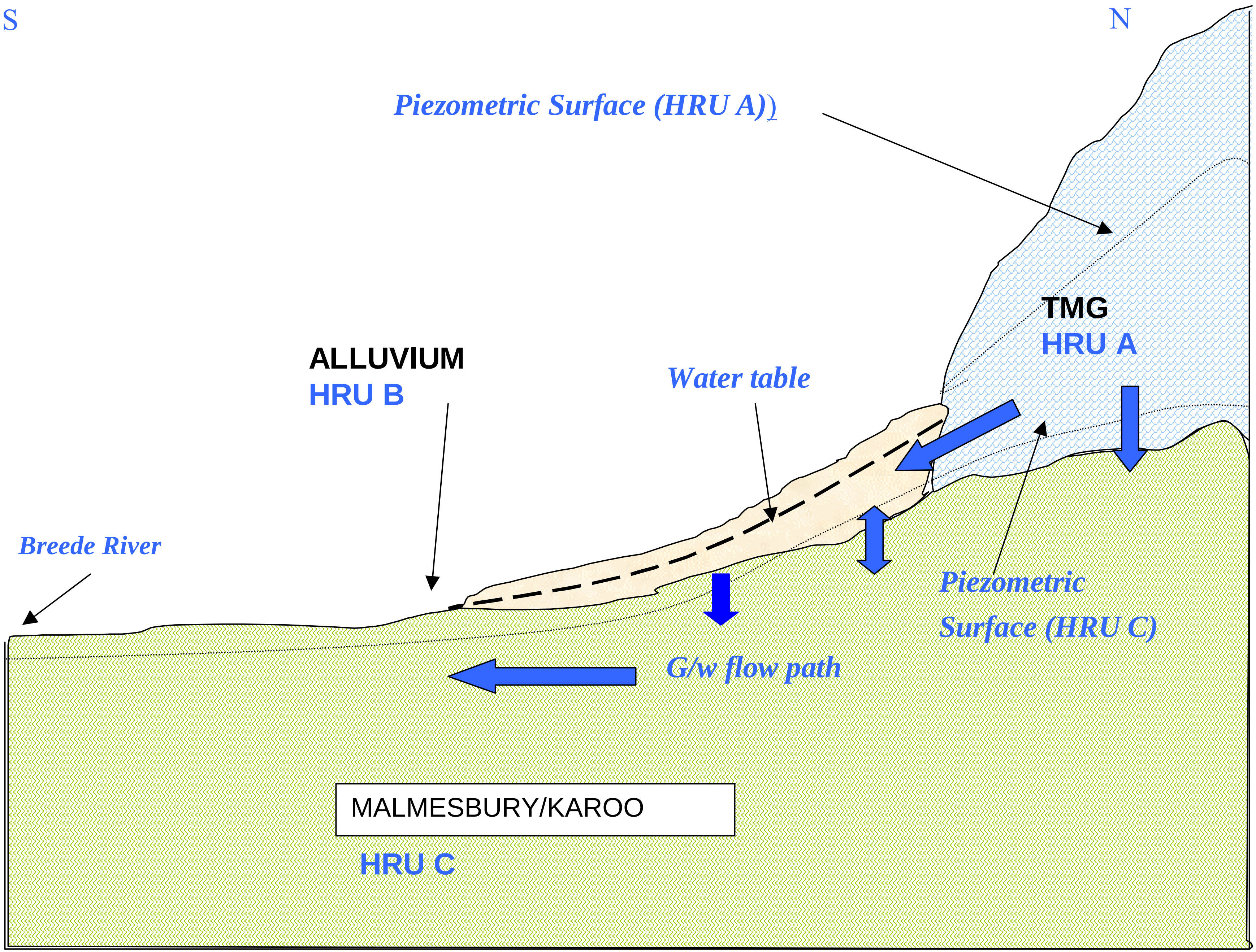


Figure 7: Cross-section through water resource area 2 from the Langeberg Mountains to the Breede River

In the Nuy and Nonna catchments alluvial aquifers are limited and most abstraction is from TMG and Malmesbury Group aquifers. Boreholes are usually situated high up in the mountain kloofs and drilled to depths of from 80m to 150m. Artesian conditions have been reported in some instances but groundwater levels are generally from 10m to 20m below surface. Pumping (or dynamic) groundwater levels are approximately 40m to 50m below surface and typically recover to pre-pumping levels after winter recharge. The estimated volume abstracted in catchment H40C is 1,1 Mm^3/a (0,6 Mm^3 from eight boreholes and one pit in Nonna catchment and 0,5 Mm^3/a from seven boreholes in the Nuy catchment).

The current groundwater usage status of unit B (De Wet alluvial aquifer) is class F (i.e. > 95% of groundwater allocation) even when the Usable groundwater contribution from Unit A is added to Unit B. The constant groundwater levels that are reported from shallow abstraction pits close to the Hex River suggest the important role of baseflow from the TMG and surface flow from the Hex Valley has in recharging the De Wet aquifer. The current status management classes for Unit A (TMG) is A and Unit C (Malmesbury Group) is B.

Groundwater quality and environmental impacts

Karoo aquifers in the southern part of water resource area 2 tend to have salinity levels that render them unsuitable for irrigation of vineyards and orchards. This is a result of saline formations in the Karoo Group, distance from recharge areas and low permeability. The thin unconsolidated sand deposits overlying large parts of the southern part of the area are not considered aquifers. These deposits are generally less than 6m in depth and the presence of groundwater in this shallow alluvium in summer due to seepage from irrigation. This seepage results in significant return flows to and salinisation of the rivers, in particular of the middle Breede River.

3.3.5 Management Class

The overall groundwater status is C (moderate volumes of groundwater usage with little negative impact apparent). The desired management class is set as 'B' requiring that monitoring be instituted and a review takes place in three years.

3.3.6 Groundwater Allocation

The groundwater allocations are presented in Table 9 with more information provided in Table 10 (for H20G and H) and Table 11 (for catchment H40C). The groundwater allocation for Unit B is only 0,09 Mm^3/a whereas the estimated abstraction exceeds 1 Mm^3/a. The low allocation does not reflect the fact that recharge to the alluvium from the TMG (Unit A) and flow in the Hex River supplies most of the abstraction from the alluvium. This example illustrates how the current methodology for IRD does not account for surface-groundwater interaction. In the case of the De Wet alluvial aquifer, the groundwater allocation should be increased by addition of the Usable groundwater contribution of Unit A (TMG) since baseflow from the TMG continuously feeds the alluvial aquifer. This still means that the abstraction exceeds the allocation and that the Reserve is likely to be affected in the De Wet area.

The level of confidence in these allocations is moderate (medium) as there is detailed information from exploration of the catchment in which most boreholes have been located and their details captured on database. In the case of the De Wet area, this was done during the Hex Valley hydrocensus (Papini *et al*, 2001) and for quaternary catchment H40C information was supplied by irrigation board managers and farm owners.

Groundwater consumption estimates

The estimates of groundwater consumption are based on information provided by the Worcester East Irrigation Board in the case of the Nonna and Nuy catchments and from the Hex Valley hydrocensus for quaternary catchments H20G. The groundwater allocations, consumption estimates and groundwater volumes still available for allocation are presented in Table 9. The overall groundwater consumption is less than 20% of the total allocation. This allocation is available from the TMG and, to a lesser extent, from the Malmesbury Group aquifers. Abstraction should be limited and possibly reduced from the alluvial aquifer if the Reserve is maintained in these areas.

TABLE 9 : GROUNDWATER ALLOCATION, ESTIMATED USE AND AVAILABLE ALLOCATION IN WATER RESOURCE AREA 2

QUATERNARY CATCHMENT	GROUNDWATER ALLOCATION (Mm^3/a)	ESTIMATED GROUNDWATER USE (Mm^3/a)	ALLOCATABLE GROUNDWATER (Mm^3/a)
H20G and H	8.4	1.5	6.9
H40C	6.8	1.1	5.7
Total	15.2	2.6	12.6

TABLE 10: DATA SHEET FOR QUATERNARY CATCHMENTS H20G AND H (HEX RIVER) OF WATER RESOURCE AREA 2

BOUNDARIES AND TYPING		MANAGEMENT CLASS		RECHARGE			ADJUSTMENT		GROUNDWATER ALLOCATION
Homogenous Response Units	**Geohydrological Region Typing**	**Current Status**	**Desired Class**	**Area Km^2**	**Recharge Method**	**Annual Recharge (Mm^3)**	**Low Maintenance Baseflow Adjustment[1](Mm^3)**	**Usable groundwater contribution[2] (Mm^3)**	**Groundwater Allocation (Mm^3)**
Unit A	Stream flow	A	a	60.18	%MAP x geological coefficient	6.40	1.06	0.9	6.24
Unit B	Stream flow and high volume abstraction	E	c	4.86	%MAP x geological coefficient	0.10	0.02	0.01	0.09
Unit C	High volume abstraction	B	b	83.22	%MAP x geological coefficient	2.08	0.34	0.29	2.03
	Saline Water	A	a	25.85	%MAP x geological coefficient	0.54	0	0.07	Exclusion
TOTALS				174.11	9.12		1.42	1.27	8.36

1. Baseflow adjustment = recharge$_{GRT}$/ recharge$_{(H200)}$ x IFR$_{(H200)}$.
2. Usable groundwater contribution = recharge$_{H20G}$ / recharge$_{(H200)}$ x Usable groundwater contribution.

Unit A: Mountain Recharge areas (TMG);
Unit B: Alluvial deposits;
Unit C: hill slope and valley bottom fractured rock aquifers (Malmesbury and Karoo).

TABLE 11 : DATA SHEET FOR QUATERNARY CATCHMENT H40C (NUY AND NONNA RIVERS) OF WATER RESOURCE AREA 2

BOUNDARIES AND TYPING		**MANAGEMENT CLASS**		**RECHARGE**			**ADJUSTMENT**		**GROUNDWATER ALLOCATION**
Homogenous Response Units	Geohydrological Region Typing	Current Status	Desired Class	Area Km^2	Recharge Method	**Annual Recharge** (Mm^3)	Low Maintenance Baseflow Adjustment^1(Mm^3)	Usable groundwater contribution^2 (Mm^3)	Groundwater Allocation (Mm^3)
Unit A	Stream flow	B	b	47.6	%MAP x geological coefficient	4.56	0.11	0.67	5.12
Unit C	High volume abstraction	D	c	62.7	%MAP x geological coefficient	1.46	0.04	0.22	1.64
	Saline Water	A	a	161.5	%MAP x geological coefficient	3.06	0.07	Exclusion	Exclusion
TOTALS				271.8	9.08		0.22	0.89	6.76

Baseflow adjustment = recharge$_{GRT}$ / recharge$_{(H40A+B+C)}$ x IFR$_{(H40A+B+C)}$.
Usable groundwater contribution = recharge$_{GRT}$ / recharge$_{(H40A+B+C)}$ x Usable groundwater contribution.

Unit A: Mountain Recharge areas (TMG);
Unit C: hill slope and valley bottom fractured rock aquifers (Bok and Karoo).

4. CONCLUSIONS

Determinations of the groundwater component of the Reserve have been carried out at an intermediate level for two water resource areas in the upper Breede Basin from Wolseley to Nuy and at a rapid level for twelve areas for the whole of the Breede Basin. The method used for the intermediate and rapid level determinations are similar except that at the intermediate level, the water resource unit is divided into smaller units based on geohydrological considerations and the groundwater allocation in each unit is determined.

The groundwater contribution to baseflow has been estimated using hydrograph separation of naturalised stream flow series from 1927 to 1990. In the rapid level determinations this volume (including basic human needs in the Reserve) has been expressed as a % of the recharge potential at the request of the Department of Water Affairs and Forestry. Water requirements for basic human needs have not been incorporated in the reserve determinations as they represent a negligible percentage of the total groundwater allocation

The groundwater contribution to baseflow provides a minimum recharge value in the selected groundwater areas (and quaternary catchments). Using the groundwater contribution to baseflow as an estimate of recharge discounts the storage in aquifers (that makes them so valuable in years of below average run-off) and implies that the only the 'usable groundwater contribution to river flow' is available for allocation (i.e. the monthly difference between the groundwater contribution to baseflow and the IFR low maintenance flow). The recharge estimate used in this investigation incorporates the concept of storage (as in the Harvest Potential) and is best termed as an average annual recharge potential.

4.1.1 Reliability of the Results

The reliability of the results is based on the accuracy of the estimates of recharge and groundwater contribution to baseflow. Both estimates are hypothetical and, in the case of recharge, based on current understanding of the distribution of recharge and storage capacity of the aquifers in the Breede Basin. The groundwater contribution to baseflow (assurance flows are provided in Appendix B) has been estimated from hydrograph separation of modelled surface flow data (naturalised). The results cannot therefore be considered as highly reliable; they are preliminary and should be regularly reviewed in light of monitoring results and the results if specialist studies.

4.1.2 Implications of the Reserve for Groundwater Exploitation in the Basin

The rapid level determination for the Ceres basin indicates that registered groundwater use exceeds the groundwater allocation. This requires a higher level reserve determination be carried out (including a detailed hydrocensus and monitoring implemented) before new licenses are approved. In the Wolseley and Moordkuil resource areas, approximately two-thirds of the groundwater allocation is registered whereas in all the remaining areas, less than 50% is registered. This implies that there is future potential for groundwater exploitation in the Breede Basin, although possibly not in the Ceres basin. Water quality constrains the use of groundwater for irrigation in many parts of the middle and lower Breede Basin.

The groundwater allocation is based on the average annual recharge minus the low maintenance baseflow. Quantification of the groundwater allocation in each homogenous response unit provides an estimate of the 'Safe Yield' that may be abstracted from that unit in average conditions without compromising the in-stream flow requirements (low maintenance flow). An adjustment to the groundwater allocation is proposed. The adjustment is termed the 'usable groundwater contribution to river flow' and is equal to the average monthly groundwater contribution to baseflow minus the monthly IFR. This allocation should only be abstracted in the months that it is available.

Groundwater use estimates have been based on information from the registration of water users in the Breede Basin. These estimates of groundwater use have been abstracted from the groundwater allocations to indicate remaining allocation available in the various study areas. The registered water use is unlikely to represent the average annual abstraction and more likely to indicate a maximum volume.

The overall current status class for water resource area 1 is C as around 35% of the groundwater allocation is used or registered. Most of this groundwater should be available for abstraction as the permeability and water quality of TMG aquifers (where the allocation is available) do not provide any constraints to use. There is no groundwater allocation remaining in the alluvial aquifers and limited allocation available in the Malmesbury Group aquifers (Unit C). Implementation of a monitoring programme focused on the alluvial aquifer and review of the IRD within three years is recommended.

Water resource area 2 is similar to area 1 in terms of the patterns of groundwater availability and use between units. However, the groundwater allocation and use is less than in water resource unit 1. The overall current status class is B as around 20% of the groundwater allocation is used or registered and there are no negative impacts apparent. Implementing a monitoring system and review of the IRD within 5 years is recommended.

4.1.3 Management Issues Relating to the Implementation of the Reserve

Three homogenous response units are recognised in the upper Breede Basin, these are the Table Mountain Group (Unit A), alluvial deposits (Unit B) and hillslope-and-valley fractured aquifers (Unit C). The alluvial aquifers are the most utilised aquifers in the upper Breede Basin whereas the TMG aquifers, where most of the groundwater allocation is available, is hardly used. This is because of practical constraints of establishing boreholes in mountainous terrain and the distance from irrigable land.

In water resource area 1 (Wolseley to Brandvlei Dam) the current status of Unit B is E because estimated groundwater use exceeds the groundwater allocation for Unit B. The current status of Unit C is D as approximately 60% of the groundwater allocation in Unit C is registered/used. A similar situation prevails for Unit B (i.e. the alluvium) in water resource area 2.

The intermediate level determinations indicate that the estimated groundwater use exceeds the groundwater allocation for the alluvial aquifers (Unit B) whereas most of the allocation from TMG aquifers (Unit A) is still available. The intermediate reserve determination methodology does not allow for considerations of surface – groundwater interaction or through flow between different units. The role of the TMG (Unit A) in supplying recharge to the alluvium (Unit B) via baseflow to streams indicates that Unit A and Unit B should be (with pre-caution) considered together when considering the groundwater allocations, or as a minimum, the usable groundwater contribution of the groundwater allocation of Unit A be added to Unit B.

The site specific conditions of every application for groundwater abstraction should be considered in addition to the status of the Reserve. In other words, the applicant must indicate the potential impact based on data obtained from test pumping, surrounding boreholes, recharge estimates and time-distance drawdown curves. The license should incorporate requirements in terms of volumes, drawdown depths and monitoring results submitted regularly to the controlling authority.

4.1.4 Further Work

There is a need to establish dedicated monitoring boreholes in proximity of rivers and streams in areas where significant abstraction is taking place. A variety of hydrogeological settings should be studied to evaluate the effects of abstraction on stream flow. Site specific data will be required including rainfall, stream flow, groundwater and stream levels and abstraction volumes could be used to improve understanding of the effects of abstraction on stream flows, the surface-groundwater interaction between homogenous response units and recharge mechanisms of geohydrological region types.

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Appendix A

Method of calculation of recharge potentials and mean annual recharge volumes per quaternary catchment.

GROUNDWATER RECHARGE

Sustainable groundwater abstraction depends on adequate recharge to replace the water being abstracted. Recharge to the bedrock aquifers may differ from recharge to the alluvial aquifers. Recharge to alluvial aquifers may take place by a combination of the following mechanisms:

- Direct rainfall infiltration on the surface
- Infiltration of irrigation water
- Influent seepage from rivers entering the alluvial plain from the bordering mountains
- Upward leakage into alluvial aquifers from the underlying bedrock and lateral flow of groundwater from the mountain fronts.

Conditions for rainfall infiltration to the alluvium are favourable over large areas of the middle and upper Breede catchment which have high groundwater-levels, and permeable surface horizons.

Recharge to the valley bottom bedrock aquifers being exploited (mainly Bokkeveld Group rocks) is effected by:

- Infiltration of rainfall into the bedrock in the higher lying mountainous areas (mainly the Table Mountain Group sandstone). This water will gravitate downgradient and feed the valley bottom aquifers. Conditions for the infiltration of rainfall on the high mountains surrounding the Breede valley are favourable as the TMG has a fractured, 'blocky' surface, with limited soil cover resulting in quick seepage through the unsaturated zone.
- Downward leakage of groundwater from overlying saturated alluvium. Downward leakage of groundwater in the alluvium to the bedrock is likely to be of most importance in those areas where large-scale abstraction takes places from the bedrock aquifer (e.g. Hex valley, Jan DuToit and Wabooms areas).
- Lateral movement of groundwater already in storage into areas dewatered by pumping

Historically most South African aquifers have estimated recharge of less than 10% of annual precipitation. Very rarely are double figures mentioned, with the Cenozoic sands being regarded as exceptional at 15 – 25%. Comparison of Cl and δ^{18}O for rainfall and groundwater from boreholes in mountains indicates recharge of 50% (Weaver et al., 1998). However, not all this recharge will reach aquifers in the valleys as it will daylight to springs and streams (baseflow), before reaching the valley floor. Modeling of the Rawsonville Goudini alluvial aquifers (Gilding and Orpen, 1978) established that for average rainfall the recharge was equal to 59.6% of the rainfall (using S of 0.08). This figure is unusually high.

During this investigation, estimates of annual groundwater recharge volumes were made using recharge based on a number of different rainfall scenarios. GIS software was used to overlay rainfall data on the catchment area, producing recharge maps based on 5% of rainfall and 10% of rainfall. Further maps were produced based on a variable recharge contribution in different rainfall areas and on a combination of variable rainfall and geology. In the case of variable recharge for different MAP, the recharge percentage varied 2 - 3% of MAP in areas with an MAP of 125 - 250 mm and 24-33% in areas with a MAP of 2250 - 3250 mm/annum. In the case of variable geology, the recharge values were multiplied by a weighted factor according to the underlying geology. The factors compared the expected recharge (under similar rainfall conditions) of different geological formations to recharge in TMG rocks. For example, in areas covered by alluvium, the recharge was multiplied by a factor of 1.6 indicating enhanced recharge potential whereas for the Bokkeveld the recharge was multiplied by 0.6 indicating reduced recharge potential. In the estimation of aquifer recharge, there are other issues which effect recharge other than rainfall and geology. These factors have not been incorporated into the recharge estimates. These factors included the type and thickness of the soil, vegetation effects, slope angle and aspect, rainfall intensity and wind effects. Although their may be disagreement over the factors used, alteration of the factors will not have a dramatic effect on the final results produced.

Table B(i) factors used in calculating recharge based on variable rainfall and variable geology.

RAINFALL (mm / annum)	RECHARGE %
< 300	3
300-600	6
600-900	9
900-1200	12
1200-1500	15
1500-1800	18
1800-2100	21
2100-2400	24
2400-2700	27
2700 –3000	30
3000-3300	33
3300-3600	36
3600-4000	40
>4000	42

GEOLOGY	VARIABLE RECHARGE FACTOR
Table Mountain Group	1.0
Bokkeveld Group	0.7
Witteberg Group	0.6
Alluvium	1.5
Malmesburg & Klipheuwel Groups	0.6
Ecca Group	0.6
Uitenhage & Dwyka Group	0.5
Granites	0.7
Any other	0.6

The estimated recharge volumes for the upper Breede Basin and Middle and Lower Breede Basin (per quaternary catchment) is presented below in table B(ii) and B(iii):

Table B(ii): Estimated groundwater recharge in the upper Breede Basin

UPPER BREEDE		**AREA** km^2	**RECHARGE** Mm^3/a	**RECHARGE PER KM^2** m^3/a
H10A	North Ceres valley	235	6.6	27,992
H10B	South Ceres Valley	163	11.1	68,283
H10C	Prince Albert/ Ceres	261	13.9	53,150
	TOTAL	**659**	**31.6**	
	Wolseley Goudini			
H10D	Tierhokkloof	97	12.6	129,688
H10E	Wit	85	20.7	243,518
H10F	Wolseley	250	20.1	80,337
H10G	Rawsonviile (N of Breed	77	7.2	93,247
H10H	Jan du Toit	189	23.4	123,638
	TOTAL	**601**	**83.9**	
	Rawsonville			
H10G	Goudini	195	18.2	93,333
H10J	Molenaars	215	67.1	312,097
H10K	Stettynskloof (Hosloot)	195	37.5	192,479
H10L	Brandvlei	96	3.3	34,727
	TOTAL	**701**	**126.2**	
	Hex			
H20A	Upper Hex	141	2.6	18,573
H20B	De Doorns	125	7.7	61,779
H20C	Lakenvallei	81	4.3	52,600
H20D	Sandrifkloof	101	6.8	67,261
H20E	Amandel	96	12.8	132,995
H20F	Sandhills	117	10.7	91,809
	TOTAL	**661**	**44.9**	
	Worcester			
H20G	Glen Heatlie	86	7.0	81,538
H20H	Worcester	90	2.4	26,388
H40C	Nuy Nonna	273	8.8	32,096
H40D	Doring	183	8.8	48,167
H40E	Hoek Modder	287	13.8	47,989
H40F		341	4.7	13,703
	TOTAL	**919**	**45.4**	
	Villiersdorp			
H60A		73	27.7	379,848
H60B		211	33.8	160,075
H60C		218	20.2	92,520
	TOTAL	**502**	**81.7**	
	Total upper breede		**414**	

Table B(iii): Estimated recharge in the middle and lower Breede Basin

MIDDLE BREEDE		**AREA**	**RECHARGE**	**RECHARGE PER KM^2**
		km^2	**Mm^3/a**	**m^3/a**
H30A		285	8.2	28,648
H30B	Montagu	316	7.0	22,094
H30C		329	10.5	31,770
H30D		128	3.9	30,530
H30E	Ashton	154	3.9	25,303
	TOTAL	**1212**	**33.4**	
	Keerom			
H40A		185	4.5	24,559
H40B		242	13.9	57,595
	TOTAL	**427**	**18.5**	
	Robertson			
H40G	Poesjenels	265	8.8	33,154
H40H	Vink	209	6.1	29,274
H40J	Robertson	205	6.1	29,726
H40K	Keisersriver	272	8.1	29,896
H40L		160	3.7	23,306
	TOTAL	**7123**	**32.9**	
	Bonnievale			
H50A		266	5.6	21,041
H50B		432	8.7	20,210
	TOTAL	**698**	**14.3**	
	Riviersonderend			
H60D		228	12.2	53,412
H60E		171	9.1	53,132
H60F		166	7.7	46,425
H60G		142	3.8	26,746
H60H		254	7.2	28,293
H60J		294	9.3	31,502
H60K		263	4.7	18,025
H60L		231	3.6	15,624
	TOTAL	**1749**	**57.6**	
LOWER BREEDE				
	Swellendam Suurbrak			
H70C		288	7.1	24,674
H70D		171	8.6	50,305
H70E		157	10.5	66,765
H70F		121	3.8	31,677
	TOTAL	**737**	**30.0**	
	Malgas			
H70A		225	4.8	21,241
H70B		154	7.4	48,269
H70G		654	10.0	15,239
H70H		400	7.0	17,572
H70J		552	8.3	14,959
H70K		146	5.7	39,010
	TOTAL	**2131**	**43.2**	
	MIDDLE AND LOWER BASIN RECHARGE			**229.82**

Appendix B

Mean monthly assurance groundwater flows

MEAN MONTHLY ASSURANCE GROUNDWATER FLOWS

Ceres (H10A, B, C)

	10%	*20%*	*30%*	*40%*	*50%*	*60%*	*70%*	*80%*	*90%*	*99%*
Oct	4.097	3.485	3.165	2.698	2.319	2.192	2.054	1.838	1.242	0.200
Nov	3.135	2.526	2.210	1.967	1.784	1.644	1.522	1.362	0.916	0.341
Dec	1.684	1.482	1.260	1.161	1.026	0.920	0.809	0.746	0.621	0.477
Jan	0.808	0.738	0.660	0.620	0.591	0.514	0.459	0.422	0.393	0.324
Feb	0.584	0.431	0.407	0.400	0.375	0.360	0.300	0.261	0.210	0.147
Mar	0.535	0.400	0.400	0.400	0.400	0.383	0.305	0.230	0.160	0.109
Apr	0.430	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.133
May	0.749	0.531	0.478	0.404	0.400	0.400	0.400	0.400	0.400	0.241
Jun	2.874	1.781	1.121	0.883	0.767	0.614	0.541	0.414	0.400	0.400
Jul	4.251	2.914	2.436	1.989	1.602	1.208	1.040	0.884	0.502	0.400
Aug	4.948	3.882	2.986	2.679	2.278	1.994	1.611	1.209	0.989	0.433
Sep	5.274	3.996	3.603	2.976	2.645	2.399	2.053	1.713	1.263	0.553

Wolsely (H10D,F)

	10%	*20%*	*30%*	*40%*	*50%*	*60%*	*70%*	*80%*	*90%*	*99%*
Oct	5.024	3.739	3.023	2.407	2.092	1.997	1.673	1.444	1.328	0.811
Nov	4.884	4.053	2.146	2.022	1.715	1.646	1.469	1.332	1.250	0.749
Dec	4.398	2.818	2.098	1.883	1.577	1.295	1.250	1.250	0.804	0.122
Jan	3.090	1.880	1.502	1.246	1.130	0.832	0.705	0.532	0.018	0.010
Feb	2.687	1.693	1.250	1.250	1.016	0.723	0.646	0.489	0.232	0.000
Mar	1.786	1.250	1.250	1.250	1.250	0.951	0.568	0.420	0.314	0.032
Apr	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.092	0.000
May	1.520	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	0.689
Jun	2.599	1.739	1.442	1.289	1.250	1.250	1.250	1.250	1.250	1.250
Jul	4.717	3.333	2.815	2.235	2.085	1.545	1.364	1.250	1.250	1.250
Aug	5.307	3.975	3.002	2.766	2.345	2.040	1.870	1.548	1.250	1.250
Sep	7.598	5.124	4.419	3.837	2.862	2.697	2.278	1.859	1.457	1.297

H100 (H10E, G,J,H,K,L)

	10%	*20%*	*30%*	*40%*	*50%*	*60%*	*70%*	*80%*	*90%*	*99%*
Oct	39.717	30.280	23.367	16.676	15.634	14.626	12.102	10.334	9.305	7.161
Nov	12.555	11.449	9.419	8.590	7.875	6.599	6.351	5.840	4.962	4.019
Dec	13.488	8.380	6.638	5.731	5.244	4.933	4.579	3.832	3.674	3.344
Jan	8.968	5.096	4.393	3.823	3.589	3.348	3.227	2.776	2.543	2.463
Feb	5.395	5.000	3.992	3.185	2.752	2.406	2.246	2.053	1.883	1.439
Mar	5.000	5.000	5.000	3.724	3.282	2.769	2.305	2.130	1.729	1.254
Apr	8.959	5.203	5.000	5.000	5.000	5.000	4.515	3.739	1.739	1.459
May	11.661	10.039	8.194	6.509	5.966	5.000	5.000	5.000	5.000	4.183
Jun	38.590	25.442	17.694	15.405	14.015	10.973	6.675	5.000	5.000	5.000
Jul	79.604	53.693	45.530	38.861	37.271	30.694	23.427	17.019	7.635	5.203
Aug	76.578	59.885	53.543	51.919	47.375	37.737	35.200	30.917	19.748	8.125
Sep	62.235	54.358	45.016	41.257	32.355	27.286	23.915	21.746	16.028	12.764

H200 (Hex Valley to confluence with Breede River)

	10%	*20%*	*30%*	*40%*	*50%*	*60%*	*70%*	*80%*	*90%*	*99%*
Oct	4.774	3.423	2.866	2.453	2.209	1.820	1.452	1.041	0.710	0.129
Nov	4.063	2.752	2.285	2.044	1.748	1.575	1.316	0.886	0.749	0.082
Dec	2.907	2.340	1.832	1.493	1.394	1.172	0.983	0.776	0.601	0.026
Jan	1.867	1.456	1.053	0.886	0.796	0.750	0.583	0.486	0.419	0.006
Feb	0.976	0.739	0.634	0.511	0.412	0.370	0.330	0.280	0.216	0.000
Mar	0.829	0.562	0.400	0.366	0.323	0.293	0.232	0.200	0.153	0.000
Apr	1.086	0.465	0.367	0.306	0.255	0.241	0.200	0.200	0.200	0.006
May	1.156	0.837	0.405	0.311	0.286	0.238	0.206	0.200	0.200	0.016
Jun	2.308	1.680	0.846	0.654	0.465	0.321	0.281	0.219	0.200	0.036
Jul	3.206	2.268	1.717	1.282	0.926	0.763	0.536	0.416	0.275	0.145
Aug	4.328	3.055	2.397	2.021	1.590	1.228	0.989	0.662	0.545	0.179
Sep	4.570	3.778	2.835	2.506	2.167	1.722	1.162	0.939	0.733	0.130

Nonna / Nuy (H40A, B, C)

	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.780	0.691	0.553	0.507	0.491	0.418	0.384	0.312	0.286	0.218
Nov	0.758	0.657	0.585	0.515	0.479	0.433	0.387	0.344	0.302	0.211
Dec	0.697	0.600	0.501	0.458	0.430	0.403	0.352	0.321	0.292	0.222
Jan	0.483	0.404	0.342	0.311	0.288	0.272	0.260	0.230	0.192	0.146
Feb	0.354	0.281	0.242	0.229	0.210	0.190	0.170	0.150	0.130	0.100
Mar	0.330	0.269	0.230	0.207	0.190	0.165	0.150	0.140	0.110	0.076
Apr	0.351	0.265	0.239	0.220	0.209	0.194	0.170	0.156	0.143	0.070
May	0.494	0.295	0.271	0.247	0.221	0.206	0.194	0.181	0.157	0.132
Jun	0.484	0.386	0.291	0.262	0.232	0.211	0.189	0.172	0.159	0.150
Jul	0.606	0.491	0.403	0.299	0.279	0.240	0.228	0.206	0.179	0.150
Aug	0.702	0.563	0.454	0.419	0.368	0.310	0.281	0.235	0.211	0.183
Sep	0.795	0.652	0.531	0.474	0.429	0.385	0.335	0.284	0.250	0.208

Moordkuil (H40D,E,F)

	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	15.322	11.345	8.803	8.099	6.704	6.187	5.357	3.870	3.205	0.731
Nov	11.160	7.766	6.513	5.849	5.384	4.846	4.120	3.624	2.907	0.853
Dec	6.538	5.236	4.278	3.442	3.060	2.754	2.320	1.926	1.752	1.257
Jan	3.667	2.626	2.070	1.700	1.390	1.218	1.129	1.030	0.801	0.576
Feb	2.289	1.570	1.202	0.976	0.875	0.712	0.598	0.526	0.416	0.270
Mar	3.809	1.868	1.307	0.914	0.765	0.604	0.539	0.446	0.282	0.101
Apr	3.607	2.542	1.875	1.350	1.082	0.954	0.812	0.570	0.412	0.000
May	5.847	3.923	2.572	2.226	1.939	1.674	1.416	1.233	0.971	0.605
Jun	7.294	6.107	4.704	2.816	2.313	1.863	1.662	1.406	0.902	0.000
Jul	9.243	6.692	5.863	4.387	3.916	2.952	2.187	1.878	1.478	0.000
Aug	15.208	11.197	7.827	7.188	5.394	4.736	3.507	2.839	2.196	1.536
Sep	18.268	13.857	10.070	8.438	6.622	5.730	3.946	3.481	2.668	0.990

Robertson (H40G,H,J,K,L)

	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	3.544	2.011	1.403	1.097	1.002	0.866	0.800	0.800	0.800	0.800
Nov	2.589	1.738	1.062	0.998	0.866	0.800	0.800	0.800	0.800	0.800
Dec	1.972	1.567	1.215	0.983	0.800	0.800	0.800	0.800	0.800	0.800
Jan	1.248	1.135	0.963	0.800	0.800	0.800	0.800	0.800	0.800	0.778
Feb	1.110	0.817	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.766
Mar	1.088	0.802	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.720
Apr	0.939	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800
May	2.165	1.208	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800
Jun	3.326	1.770	1.206	0.931	0.800	0.800	0.800	0.800	0.800	0.800
Jul	2.778	1.606	1.300	0.918	0.800	0.800	0.800	0.800	0.800	0.800
Aug	2.760	1.856	1.522	1.215	0.930	0.800	0.800	0.800	0.800	0.800

Kogelmans (H30A - E)

	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.861	0.482	0.280	0.248	0.190	0.162	0.121	0.100	0.100	0.043
Nov	0.598	0.338	0.247	0.179	0.142	0.127	0.100	0.090	0.073	0.056
Dec	0.399	0.305	0.150	0.112	0.100	0.072	0.060	0.040	0.033	0.020
Jan	0.213	0.131	0.100	0.080	0.050	0.030	0.030	0.020	0.010	0.006
Feb	0.202	0.115	0.100	0.048	0.040	0.030	0.020	0.010	0.010	0.000
Mar	0.377	0.175	0.137	0.100	0.100	0.082	0.039	0.020	0.010	0.000
Apr	0.274	0.169	0.139	0.115	0.100	0.100	0.069	0.050	0.030	0.016
May	0.522	0.271	0.211	0.185	0.120	0.100	0.100	0.100	0.080	0.046
Jun	1.153	0.542	0.265	0.196	0.165	0.130	0.100	0.100	0.100	0.069
Jul	0.750	0.569	0.312	0.210	0.170	0.143	0.125	0.100	0.100	0.070
Aug	1.073	0.646	0.502	0.313	0.207	0.156	0.112	0.100	0.100	0.070
Sep	1.223	0.624	0.452	0.330	0.264	0.190	0.154	0.113	0.100	0.070

Ashton to Swellendam (H50A, B; H70A, B)

	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	6.203	5.389	4.742	4.213	3.725	3.414	2.975	2.603	2.280	2.204
Nov	5.894	5.328	4.786	4.007	3.553	3.414	3.244	2.891	2.176	1.055
Dec	6.240	5.233	4.615	3.628	3.334	3.081	2.845	2.562	1.960	1.124
Jan	4.414	3.976	3.515	2.971	2.852	2.493	2.389	2.021	1.627	0.892
Feb	3.835	2.727	2.224	1.998	1.591	1.457	1.413	1.319	0.942	0.174
Mar	3.326	3.125	2.654	2.512	1.862	1.684	1.571	1.392	1.118	0.322
Apr	2.824	2.745	2.543	2.089	1.650	1.488	1.449	1.401	0.944	0.110
May	3.317	2.876	2.672	2.170	1.995	1.637	1.295	1.217	0.833	0.571
Jun	4.223	3.526	2.873	2.594	2.389	2.084	1.773	1.528	1.180	0.712
Jul	4.149	3.853	3.582	3.366	3.082	2.547	2.066	1.743	1.585	0.789
Aug	5.257	4.987	4.302	3.872	3.647	3.078	2.517	2.151	1.863	1.754
Sep	6.490	5.033	4.696	4.385	4.012	3.551	2.905	2.581	2.212	1.959

Buffeljags (H70C, D, E, F)

	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	11.022	7.936	7.137	6.050	4.897	3.997	3.619	3.137	3.000	1.126
Nov	13.610	9.855	7.327	6.211	5.550	5.133	4.279	3.452	3.000	1.422
Dec	10.552	7.980	6.600	5.753	5.176	4.551	4.088	3.684	3.028	1.476
Jan	7.270	5.559	4.236	3.622	3.280	3.028	2.839	2.627	1.543	0.572
Feb	5.822	5.258	4.708	4.054	3.219	3.000	2.728	2.098	1.921	1.090
Mar	7.602	6.036	4.207	3.633	3.142	3.000	3.000	2.620	1.844	1.055
Apr	8.910	6.353	5.341	4.165	3.430	3.014	3.000	2.060	1.493	1.117
May	9.309	5.033	4.384	3.333	3.183	3.000	3.000	2.380	1.793	1.102
Jun	7.666	6.724	4.946	4.186	3.360	3.000	3.000	2.449	1.889	1.371
Jul	7.852	6.903	5.234	4.197	3.337	3.000	3.000	3.000	2.563	1.890
Aug	8.867	6.409	5.579	4.678	3.824	3.510	3.000	3.000	3.000	2.682
Sep	11.515	8.774	7.315	6.081	5.470	3.881	3.268	3.000	3.000	2.295

Riviersonderend (H60A - L)

	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	7.064	7.057	7.009	6.868	6.577	6.139	5.550	4.671	3.604	1.927
Nov	6.540	6.073	5.494	5.153	4.879	4.290	3.838	3.494	2.701	1.409
Dec	2.962	2.950	2.906	2.820	2.708	2.493	2.222	1.797	1.420	1.221
Jan	2.406	2.307	2.233	2.125	1.950	1.798	1.586	1.470	1.152	0.927
Feb	1.834	1.700	1.568	1.500	1.500	1.500	1.500	1.431	1.156	0.748
Mar	1.267	1.267	1.261	1.246	1.221	1.162	1.074	0.920	0.753	0.580
Apr	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.455	1.125
May	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500
Jun	2.727	2.727	2.712	2.687	2.616	2.479	2.220	1.834	1.500	1.500
Jul	5.663	5.607	5.527	5.389	5.134	5.031	4.796	3.902	2.798	1.500
Aug	7.547	6.811	6.392	6.147	5.838	5.386	5.056	4.293	3.477	1.694
Sep	12.977	11.936	11.240	10.503	8.657	7.790	7.201	5.959	5.021	2.315

Lower Breede (H70G, H, J)

	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	2.214	1.280	1.013	0.799	0.603	0.522	0.504	0.500	0.500	0.500
Nov	1.716	1.313	0.926	0.787	0.503	0.500	0.500	0.500	0.500	0.500
Dec	1.501	1.159	0.818	0.656	0.500	0.500	0.500	0.500	0.500	0.500
Jan	0.728	0.664	0.604	0.500	0.500	0.500	0.500	0.478	0.423	0.342
Feb	0.657	0.573	0.500	0.500	0.500	0.500	0.450	0.296	0.220	0.164
Mar	1.281	0.582	0.500	0.500	0.500	0.500	0.387	0.314	0.219	0.150
Apr	0.636	0.528	0.500	0.500	0.500	0.500	0.495	0.382	0.306	0.175
May	1.704	1.405	1.056	0.727	0.548	0.500	0.500	0.500	0.500	0.244
Jun	2.166	1.392	0.942	0.759	0.524	0.500	0.500	0.500	0.500	0.500
Jul	1.872	0.971	0.783	0.639	0.578	0.509	0.500	0.500	0.500	0.500
Aug	1.639	1.252	0.702	0.554	0.534	0.500	0.500	0.500	0.500	0.500
Sep	2.444	1.585	0.821	0.634	0.603	0.547	0.503	0.500	0.500	0.485

Appendix C

Hydrocensus from Water Resource Areas 1 and 2

Water Resource Unit 1

Hydrocensus of boreholes in H100 (excluding Ceres area)

Name	Lat	Long	Depth	Casing diameter	Equipment	Use	Water Level	Water Quality (EC)	Aquifer
Rawsonville Municipality	33°41’23”	19°18’49”	10m	200mm	submersible	Dom	?	37mS/m	Alluvium
Groot Eiland (wynkelder)	33°39’52”	19°18’27”	13m	-	submersible	Irr	?	31mS/m	Alluvium
Chelance	33°38’36”	19°20’18”	13m	168mm	submersible	Irr	?	29mS/m	Alluvium
Du Toit wynkelder	34°42’12”	19°16’04”	10m	?	submersible	Dom	?	37mS/m	Alluvium
Goudini wynkelder	33°41’36”	19°19’13”	34m	168mm	submersible	Dom & Irr	?	39 mS/m	Alluvium
Weltevrede Onderplaas	33°43’14”	19°20’37”	49m	?	monopump	Dom Irr	?	28mS/m	Alluvium
Waboom Kelder	33°31’45”	19°12’39”	40m	168mm	submersible	Irr	?	27mS/m	Alluvium
Therin	33°34’01”	19°14’47”	65m	168mm	submersible	Irr	?	49mS/m	Alluvium
Lakegonskop Wynkelder	33°30’50”	19°11’12”	30m	168mm	submersible	Irr	?	65mS/m	Sandstone
Rainbow chickens	33°35’19”	19°23’35”	35m	200mm	submersible	Dom & Irr	?	69mS/m	Shale & Sandstone
Dwarsrivier Correctional Services	33°28’12”	19°12’19”	150m	168mm	submersible	Dom & Irr	?	104mS/m	Shale

Water Resource Unit 2

Groundwater users in the Nonna/Nuy area (H40C)

Name of Farm	Farm Number	Type of Pump	Pumps Yield m^3/hr	Casing Diameter mm	Water Level	Use
Hamman, N.H	326R*	Submersible	5	300	?	Irrigation
Moller, PdT	330*	Submersible	30	150	?	Irrigation
Moller, PdT	341/10*	Submersible	10	150	?	Irrigation
Nonna Irrig Board	341/3*	?	70	?	?	Irrigation
Conradie, AJ	338/30*	?	50	300	?	Irrigation
Visser, DC	336R*	Submersible	46	300	?	Irrigation

** These farms have more than one borehole.*

Water Resource Unit 2

Hydrocensus of boreholes in De Wet area (H20G)

Farm Name	Farm No	Latitude	Longitude	Borehole Depth	Casing Depth	Borehole Diameter	Water level	Borehole Yield	Yearly Abstraction	EC
				m	m	mm	mbc	L/s	m^3	mS/m
NON PAREL	131\1R	33 27 58.0	19 39 32.3	130		200		3.75	27216	
NON PAREL	131\1R	33 27 55.4	19 39 37.2	130		200	21.4		0	
NON PAREL	131\1R	33 27 55.7	19 39 32.9	130		200		4	29029	
ORANGE GROVE	618	33 35 19.5	19 30 13.8	13.2	13.2	200	3	14	62832	8
ORANGE GROVE	618	33 34 56.2	19 30 22.0	6			2.5	19	62832	
ORANGE GROVE	618	33 35 22.6	19 30 31.5	6			2	7	62832	13.7
ORANGE GROVE	618	33 34 43.2	19 30 29.0	6	6	150	3	16	62832	
ORANGE GROVE	618	33 33 10.3	19 29 45.0				4.4	0.3	5518.8	165
ORANGE GROVE	618	33 35 01.6	19 29 08.0					0.3	5518.8	
ORANGE GROVE	618	33 33 25.4	19 29 35.4					17	0	3.3
ORANGE GROVE	618	33 35 09.0	19 29 31.8				6		0	
GOEDEHOOP	183\12	33 35 12.4	19 30 34.7	7	7	200	3	12.5	44247	7
GOEDEHOOP	183\12	33 35 11.9	19 30 37.2	7		105	4	12.5	44247	12
GLEN HEATLIE	183\2	33 34 38.7	19 30 37.8	4.6	4.6	150	2	15	52066	
GLEN HEATLIE	183\2	33 34 11.5	19 30 35.7	11.55	11.5	200	3	22.5	52059	
ERIESLAND	319\53	33 35 43.4	19 31 13.7			100	0.5	3	8400	133.3
RHEEBOKSKRAAL	319\59	33 35 45.7	19 30 46.9	4			0.5	8	40467	5.5
RHEEBOKSKRAAL	319\59	33 35 36.8	19 30 36.5	4			2	8	40467	17.9
RHEEBOKSKRAAL	319\59	33 35 39.1	19 30 59.3	4			0	3	16800	70
BONHEUR	319\14R	33 35 52.9	19 30 45.7	10	10	200	2	11	35000	37.5
BONHEUR	319\14R	33 35 50.8	19 30 52.8	2	2	800	1	33	379015	17.5
GOEDEHOOP	319\21	33 35 27.3	19 30 42.2	8	8	900	2	37.5	34706	17
GOEDEHOOP	319\21	33 35 22.1	19 30 43.0	16.5	16.5	150	2	37.5	34706	18
GOEDEHOOP	319\21	33 35 20.2	19 30 39.4	16.5	16.5	200	3	37.5	34706	23
MOOIHOEK	318\2	33 35 30.9	19 30 36.1	6	6	5	2.5	12.5	71400	12.9
BRUGPLAAS\TWEEFON	319\71	33 36 23.2	19 30 47.4	8	8	10	3	9.4	56854	13
BRUGPLAAS\TWEEFON	319\71	33 36 17.6	19 30 49.8			225	2.5	9.4	56854	34.4
BRUGPLAAS	319\71	33 36 28.7	19 30 51.7			1575	3	9.4	56854	48.8
BRUGPLAAS	319\71	33 36 32.1	19 31 04.5				0	3	0	16.9

Hydrocensus of boreholes in De Wet area (H20G) contd.

Farm Name	Farm No	Latitude	Longitude	Borehole Depth	Casing Depth	Borehole Diameter	Water level	Borehole Yield	Yearly Abstraction	EC
				m	m	mm	mbc	L/s	m^3	mS/m
LOUZAAN	317R	33 35 07.7	19 30 55.7	0			0	20	43820	3.6
LOUZAAN	317R	33 35 06.3	19 30 37.0	8	8	125	2.6	17.5	43820	8.8
LOUZAAN	317\R	33 35 07.3	19 30 42.9	4.6		1050	2.5	1.25	7560	8.2
LOUZAAN	317\1	33 35 15.4	19 30 43.4	15	15	200	2.5	16.6	100401	17.8
DE WET SPORTGROND	319\21	33 36 23.8	19 30 28.2	80			2.6	8.3	6562.5	17.8
DE WET KELDER		33 36 22.3	19 30 37.0			160	2.6	0.1	459.9	
BARBRA NEL TRUST		33 36 42.3	19 30 30.6				0		0	3.2
ZEEKOEIGAT	183\4	33 34 03.5	19 30 32.6	17	17	200	2.5	8	74651.5	
ZEEKOEIGAT	183\4	33 34 16.7	19 30 28.8	17	17	200	2.6	8	74665.5	
BOSTHKLOOF	328\4	33 35 43.9	19 32 41.5	100		150	6.6	1.4	18144	
BOSKLOOF	328\4	33 35 34.0	19 33 10.1	6			4		43533	7.1
BOSCHKLOOF	328\4	33 35 44.1	19 32 33.5	6			2.5	3	43533	9.7
BOSCHKLOOF	328\4	33 35 49.2	19 32 22.1	6			3.8	3	43533	20.5
ZEEKOEIGAT	183\4	33 34 18.7	19 30 23.2	17	17	200	2.5	11	74665.5	
BROEKRIVIER	41	33 24 36.5	19 44 44.2	114	8	200	11.86			3.2
								TOTAL	**1,952,808**	